

## **Treball Final de Grau/Carrera**

**Realitzat i defensat a UC - Leuven Limburg (nom universitat) de Bèlgica  
(país)**

**Estudi:** Grau en Eng. en Tecnologies Industrials Pla 2010

**Títol:** Design and Construction of a Mobile Renewable Energy Unit

**Document:** Memòria

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**Convocatòria** (mes/any): Juny/2017

Dear reader,

We are Carles Adell and Nora Fonseca, authors of this project and Exchange students from the University of Girona (Spain). This is our senior year of Industrial Engineering. As senior students, we had to do our final project, and we decided to do it abroad.

Before arriving to Hasselt, we were students in Girona, we studied there our whole lives. Apart from studying we both enjoy being with new people, discovering novel places and travelling. The European Erasmus+ exchange program has given us the opportunity of living an amazing opportunity in which we could gladly achieve both personal and academical goals.

In the UCLL we have taken part of the Energy Department, in which we have been part of a project that consisted on designing and building a Mobile Renewable Energy Unit. It is said that being far from home is difficult, we guess that we were lucky to find such a good department, because they absolutely made our integration a lot easier. That is the reason we are deeply thankful to Thomas Vanhove for leading us during this period. We also would like to show our gratitude to Thomas Henderickx and Peter Vanhout, who have made our stay in the Energy laboratory as pleasant and enjoyable as possible.

We also place on record our sincere thank you to Jan Elsen for helping with the design of the prototype and building it, and Eric Dirckx for helping with everything he could in the workshop and for teaching us useful tips whenever he had occasion to.

Finally, we take this opportunity to express our gratitude to all those who made possible we could be here presenting our thesis.

Cordially,

Carles and Nora

## Centre of Expertise – Energy

The UCLL (University Colleges Leuven – Limburg) has several departments that carry out different projects and activities. In this case, we took part in a project managed by the Energy Department, which is part of the group Management and Technology. Its purpose is to stay on top with the latest trends and developments in the field of energy technologies and spread academic knowledge using their projects as examples.

On the one hand, the centre of expertise Energy focuses on research, services, and dissemination of research results to education with regards to new energy technologies such as electrical energy and thermal energy.

The centre disposes a functional grid that can be used for carrying out simulation exercises, as well as for testing different combinations of the applications of sustainable energy and conserving in energy in battery system and hydrogen gas. For industrial networks, energy has a certified education and services center for ProfiBus and ProfiNet and it states on European Energy Management trainings. Energy collaborates with ACRO on aspects of vision, robotics, and automation on an industrial scale.

On the other hand, the laboratory of thermal energy (in Houthalen) is used for experimenting with testing and cooling techniques, experts pool, expertise in cooling and heat pump technologies and geothermal energy. It focuses on energy – saving technologies and natural cooling systems. It also organizes trainings for air – condition experts, among other activities.

# INDEX OF CONTENTS

PROLOGUE.....	9
Chapter I. Preliminary Study	
1 INTRODUCTION.....	10
1.1 Mobile Renewable Energy Unit: Definition and Applications .....	10
1.2 Already Done.....	10
1.2.1 Mobile Renewable Energy Unit, Florida Solar Energy (FSE) .....	11
1.2.2 LT – 24LI, Mobile Solar Energy.....	11
1.2.3 Trinity – Skajaquoda Research Group.....	12
1.2.4 Mobile Hybrid Power System (MHPS), Enderel.....	13
1.2.5 Mobile Power Station BST – MT – HP, Black Sage Technologies .....	13
1.2.6 Off – Grid Solar Trailer Power Systems, SunWize® .....	14
2 COMPONENTS .....	15
2.1 PV Solar Panels.....	15
2.1.1 Relationship among PV cell, module, and array.....	15
2.1.2 Solar Cell Technologies.....	15
2.1.3 PV Electrical Characteristics.....	16
2.2 Batteries.....	18
2.2.1 Introduction.....	18
2.2.2 Batteries parameters definitions.....	18
2.2.3 Rechargeable Batteries Technologies.....	20
2.3 Inverter .....	26
2.3.1 Defining parameters.....	26
2.3.2 Examples.....	26
2.4 Wind Turbine .....	28
2.4.1 Wind Turbine technology .....	29
2.4.2 Wind energy conversion.....	29
2.4.3 Parts of a turbine.....	30
2.4.4 Control and Power Limitation .....	30
2.4.5 System Power Characteristics .....	31
2.4.6 Wind Turbine Generators.....	31
2.4.7 Small wind turbines examples.....	33
2.5 Generator.....	37
2.5.1 Classification based on field flux production.....	38
2.5.2 Classification base on the combustible Used .....	39
2.6 Charge Controller .....	41

2.6.1	Solar Charge Controllers .....	41
2.6.2	Wind turbines charge controllers .....	42

## Chapter II. Preliminary Designs

1	SPECIFICATIONS AND FIRST DESIGNS .....	43
1.1	Comparison .....	45
2	THE ALTERNATIVE .....	46

## Chapter III. Photovoltaic System Design

1	PV MODULES .....	47
1.1	Calculation of the energy produced .....	47
2	BATTERIES .....	48
3	SOLAR BATTERY CHARGER .....	49
4	PV ARRAY CONFIGURATION .....	50
5	INVERTER .....	52
6	OTHER DEVICES AND CONNECTIONS BETWEEN THEM .....	53
7	WIRING .....	55

## Chapter IV. Structural Designs and calculations

1	OBJECTIVE .....	56
2	PROCESS & RESULTS .....	56

## Chapter V. Building Process

1	TOOLS & MATERIAL .....	58
2	PROCEDURE .....	61
3	ELECTRIC ASSEMBLY .....	64

Chapter VI. Conclusions

1 OUTCOME..... 66

2 CLOSURE..... 66

Chapter VII. References

1 BIBLIOGRAPHY ..... 67

2 WEBOGRAPHY ..... 68

Chapter VIII. Annexes

## INDEX OF FIGURES

Figure 1. Florida Solar Energy, Solar Panels, Image .....	11
Figure 2. Florida Solar Energy, Solar Plant, Sketch .....	11
Figure 3. Mobile Solar, LT - 24 LI, 2015, Image .....	12
Figure 4. Skajaquoda Research Group, 2014, Trinity, Image .....	12
Figure 5. Enderel, 2014, MHPS - 80, Image .....	13
Figure 6. Enderel, 2014, MPHS, Diagram .....	13
Figure 7. Black Sage Technologies, 2016, BST – MT – HP, Image .....	14
Figure 8. SunWize, 2017, Off - Grid Solar System Closed, Render .....	15
Figure 9. SunWize, 2017, Off - Grid solar system Opened, Render .....	15
Figure 10. LED Watcher, 2017, Monocrystalline Solar Panel and Cell, Image. ....	16
Figure 11. LED Watcher, 2017, Polycrystalline Solar Panel and Cell, Image .....	16
Figure 12. LED Watcher, 2017, Thin - Film Solar panel and cell, Image .....	16
Figure 13. Identification of $I_{sc}$ , $V_{oc}$ , $I_{mpp}$ , $V_{mpp}$ and $P_{mpp}$ on the I-V and P-V curves. ....	17
Figure 14. I-V curve from Kyocera KC200GT PV module: (a) under constant temperature and (b) under constant irradiance.....	18
Figure 15. Depth of Discharge lifetime for a shallow cycle battery graph from pveducation.org	20
Figure 16. Lead acid batteries, www.directindustry.com .....	21
Figure 17. Performance of standard NiCd (7.2V - 900mAh) from www.batteryuniversity.com ..	22
Figure 18. Nickel - Cadmium batteries, from www.changhongbatteries.com .....	22
Figure 19. Performance of NiMH (6V - 95mAh) - www.batteryuniversty.com .....	23
Figure 20. Nickel metal hydride cell - www.rechargebatteries.org .....	24
Figure 21. Cycle Characteristics of IHR18650C by E-One Moli (3.6V - 2,000mAh), www.batteryuniversity.com .....	25
Figure 22. LED Watcher, Li - on batteries, Image.....	25
Figure 23. Victron Energy, 2016, Phoenix Inverter 3-5kVA, Image. ....	27
Figure 24. Victron Energy, 2017, Phoenix Inverter 3 – 5kVA, Circuit Diagram .....	27
Figure 25. Victron Energy, 2016, Phoenix Inverter 1.2 – 2 kVA, Image .....	28
Figure 26. STIEBLER, M. 2008, Wind Energy Systems for Electric Power Generation, Diagram.	30
Figure 27. CARRIVEAU Rupp (In Tech), 2012 Wind Turbine scheme, 3D Drawing .....	30
Figure 28. STIEBLER Manfred, 2008 Curves for a pitch controlled and stall – controlled systems, Diagram.....	31
Figure 29. CARRIVEAU Rupp, 2012, DC Generation system, Diagram.....	32
Figure 30. CARRIVEAU Rup. (In Tech), 2012, Two induction generator systems, schematic drawing. ....	33
Figure 31. Missouri Wind and Solar Wind Turbine (www.mwands.com).....	34
Figure 32. Wattages derived at on a 19m wind turbine tower with no obstructions (www.mwands.com).....	34
Figure 34. Wind Turbine Bee 800, www.bornay.com .....	35
Figure 33. Bornay, PV - Curve of Wind Turbine Bee 800 (www.bornay.com) .....	35
Figure 35. Scheme of the different components using the Wind leaf .....	36
Figure 36. Wind Challenge, The Wind leaf Turbine.....	36
Figure 37. Wind Challenge, PV - curve of the Wind leaf Turbine .....	37
Figure 38. Electrical Engineering Community, 2013, Flux generation by Faraday's Law, Sketch. .....	37
Figure 39. Electrical Engineering Community, 2013, Separately Excited Generator Circuit, Sketch .....	38
Figure 40. Electrical Engineering Community, 2013, Shunt Generator Circuit, sketch.....	38
Figure 41. Electrical Engineering Community, 2013, Series Generator Circuit, Sketch. ....	38
Figure 42. Electrical Engineering Community, 2013, Commutatively Compound Generator Equivalent Circuit, Sketch.....	39
Figure 43. ATG, 2012, ATG Multifuel 3SP Power Generator, Image .....	39

Figure 44. WBDG, 216, Direct Combustion/Steam Turbine System for Electricity Generation, Diagram.....	40
Figure 45. LEAF Generator, 1999, Gasifier, Image. ....	41
Figure 46. The Maximum Power Point moves to the left and downwards with the increasing temperature (www.victronenergy.com) .....	42
Figure 47. MREU folded – Design 1.....	43
Figure 48. MREU unfolded - Design 1.....	44
Figure 49. MREU Folded – Design 2 .....	44
Figure 50. MREU unfolded - Design 2.....	45
Figure 51. MREU unfolded - Design 3.....	46
Figure 57. Calculation solar Blog, 2014, Diagram. ....	48
Figure 58. PV Parallel configuration.....	50
Figure 59. Series Configurations .....	51
Figure 60. PV array drawing .....	52
Figure 61. Connections between electric devices, drawing .....	53
Figure 55. Right - angled triangle structure (folded), CAD drawing.....	56
Figure 56. Trapezoidal structure profile (folded), CAD drawing .....	57
Figure 52. L profile drawing, Autodesk Inventor .....	58
Figure 53. Solar Profile drawing, Autodesk Inventor .....	59
Figure 54. ISO Rectangular Profile, Autodesk Inventor .....	59



## INDEX OF IMAGES

Image 1. Automatic Saw, VM Service .....	60
Image 2. Automatic Saw, VM Service .....	60
Image 3. Set – Square .....	60
Image 4. Protractor .....	60
Image 5. Drilling Machine, IMA Malilla.....	61
Image 6. Trapezoidal Porch.....	61
Image 7. Parallel Porches.....	62
Image 8. Prototype with crossed beams and first folding part.....	62
Image 9. Reinforced corner 1 .....	63
Image 10. Reinforced corner 2 .....	63
Image 11. Final Prototype seen from the bottom .....	63
Image 12. Final Prototype unfolded .....	64
Image 13. Building of the case process .....	65

## INDEX OF TABLES

Table 1. MREU Characteristics .....	11
Table 2. LT - 24 LI Characteristics .....	12
Table 3. Trinity Characteristics.....	13
Table 4. MHPS Characteristics .....	13
Table 5. BST – MT – HP Characteristics.....	14
Table 6. Off - Grid Solar Trailer Power System Characteristics .....	14
Table 7. Lead Acid Characteristics.....	21
Table 8. Nickel - Cadmium Characteristics .....	21
Table 9. Nickel - metal hydride Characteristics.....	23
Table 10. Nickel - Zinc Characteristics .....	23
Table 11. Lithium - ion Characteristics .....	24
Table 12. Phoenix Inverter 3 -5 kVA Characteristics .....	27
Table 13. Phoenix Inverter Compact 1.2 - 3kVA Characteristics .....	28
Table 14. Missouri Rebel Freedom 5 Blade Wind turbine characteristics .....	34
Table 15. Bornay Wind Turbines Characteristics .....	35
Table 16. Wind leaf wind turbine Characteristics.....	36
Table 17. ATG Multifuel 3SP Characteristics.....	40
Table 18. Comparison between Design 1 and 2 .....	45
Table 19. PV Modules Characteristics .....	47
Table 20. PV Data (Belgium) .....	47
Table 21. Brussels Average Solar Insulation. ....	47
Table 22. Batteries Characteristics .....	49
Table 23. Controller Characteristics.....	50
Table 24. PV Panels Characteristics.....	51
Table 25. PV Panels Characteristics.....	51
Table 26. Inverter Characteristics .....	53

## Prologue

Sustainability has turned into a common concept in our lives. Therefore, sustainable development has become the challenge of dedicated environmentalist and industrialist alike. Nowadays, our society relies on energy. This project seeks to merge both concepts in one unique equipment. The MREU also called Mobile Renewable Power Station is a system that is available to provide energy from different kind of green energies. Another goal of this project is inspiring young generations in green energies development.

The MREU is mainly composed by one or more power sources, in this case we used solar panels, pure plant oils (PPO), and wind turbines. It needs to have an energy storage system and other energy management devices to guarantee its good functionality.

We have divided the project in different chapters: Preliminary Study, Preliminary Designs, Photovoltaic System Design, Structural Design and Calculations, Building Process, and Conclusions. The first two chapters will help us know and study what's already in the market and to analyze the characteristics that the machine should have to be well – built. Prices and materials have been also considered. After having an idea of what has been done before, we describe the electric and structural design.

Finally, we portray the building process, with the material we have used and the process to follow. It is important to remark that we could not finish the construction of the MREU before the delivery of this thesis, due to delays on delivering dates of some materials. Thus, we have described the process with pictures until as far as we got, and then we have defined the process we will follow to finish the MREU.

To sum up, we consider it important to point out the goals achieved during this project. Apart from the obvious technological goal of building the MREU, it's important to highlight the awareness in schools and high schools that this can have. Serving as an inspiration source to choose a career in modern green technologies. With this project, we will try to achieve all these goals all in one project.

# I. Preliminary study

## 1 INTRODUCTION

### 1.1 MOBILE RENEWABLE ENERGY UNIT: DEFINITION AND APPLICATIONS

A Mobile Renewable Energy Unit (MREU), also called Mobile Renewable Power Station (MRPS) is a system that is available to provide energy from different kind of energy sources such as solar, wind or fuel. Therefore, that means it can supply energy without being connected into the general grid. As it is mobile, it can be brought to provide energy to the most isolated places, or also it can be used in connected places when a failure occurs in the general grid.

A MREU is mainly composed by one or more power sources (e.g. solar panels, diesel generator, etc.), an energy storage system (batteries) and a controller. It has a structure in which stands all the components, and needs to be mobile to transport it to any place.

A mobile energy unit has application in the following fields:

- Medical equipment
- Emergency Services
- Scientific research
- Communications
- Military bases
- Wild Live
- Construction
- Agriculture
- Events and Entertainment
- Educational use

### 1.2 ALREADY DONE

Currently, there are many kinds of Mobile Renewable Energy Units that have been already built. However, most of them are based in solar energy, and so they are called mobile solar power units. There are also mobile wind turbines, which make the same function. There are only a few MREUs like the goal of this project: a mobile energy unit that have different power sources. Most of them are customized and make to order products.

Shown below some mobile power systems that currently are in the market.

### 1.2.1 Mobile Renewable Energy Unit, Florida Solar Energy (FSE)

Florida Solar Energy has developed a MREU for military bases powered by solar energy and a diesel generator.

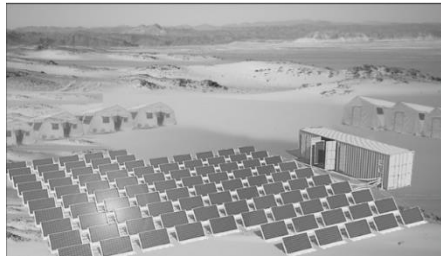


Figure 2. Florida Solar Energy, Solar Panels, Image

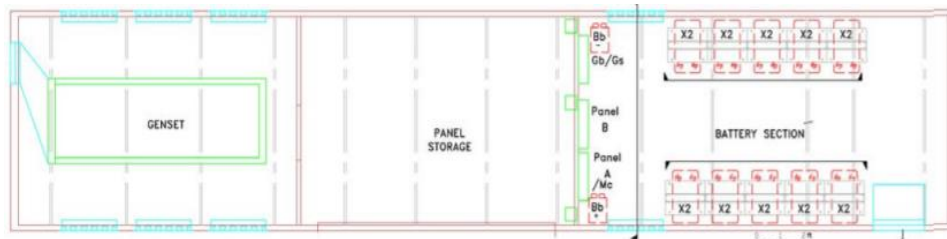


Figure 1. Florida Solar Energy, Solar Plant, Sketch

Power Sources	Solar Diesel Generator
Solar	100 panels of 300Wp each
Diesel Generator	35 KW
Energy Storage	Battery module of Lithium, 100Kwh storage capacity.
Dimensions	System footprint ~18m x ~21m

Table 1. MREU Characteristics

### 1.2.2 LT – 24LI, Mobile Solar Energy

Mobile Solar is an American company based in California. Their specialization is designing and manufacturing generators that can capture, store, and distribute electricity generated by the sun. This company offers distinct types of products with the same aim.



Figure 3. Mobile Solar, LT - 24 LI, 2015, Image

<b>Energy Source</b>	Solar Panels	Mono Crystal, 2x225W
<b>Output Power</b>	10.8 kWh – Lithium – ion Batteries	
	Voltage 120 VAC	
<b>Inverter</b>	3.5 – 6 kW	
<b>Dimensions</b>	Open: Hight Tower 7m Powder Coated Steel, 1590kg	
<b>Price</b>	\$31,024 – \$38,780	
<b>Others</b>	4 – Slide out, Crank down Outriggers	

Table 2. LT - 24 LI Characteristics

### 1.2.3 Trinity – Skajaquoda Research Group

This product is designed by a research group named *Skajaquoda* placed in Minnesota (USA). In 2014 the prototype was finished and by 2015 they began to sell it in the market.

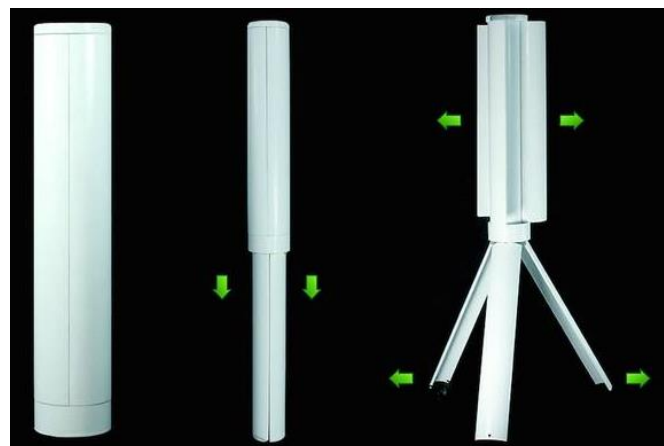


Figure 4. Skajaquoda Research Group, 2014, Trinity, Image

Energy Source	Wind	
	Blades	3, Aluminum and Plastics
Output Power	15W (multiple USB outputs with 1A and 2.1 A)	
Energy Storage	15Ah	
Dimensions	Hight 584.2 mm - Ø305mm – 1.13 kg	
Price	US \$75,000	
Others	LED battery indicators, operates in DC	

Table 3. Trinity Characteristics

#### 1.2.4 Mobile Hybrid Power System (MHPS), Enderel

The MHPS of ENDEREL is a trailer with an energy storage system with a generator in which different power sources can be connected, such as solar panels or a wind turbine.

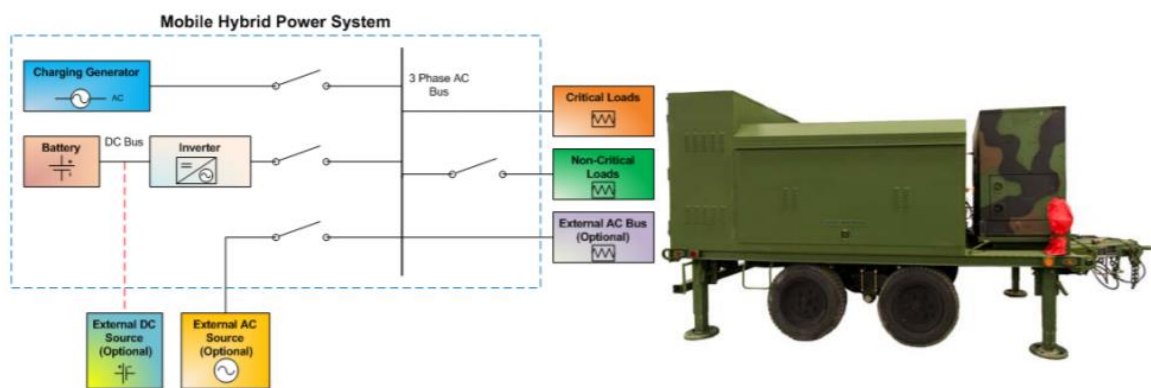


Figure 6. Enderel, 2014, MPHS, Diagram

Figure 5. Enderel, 2014, MHPS - 80, Image

Energy Sources	Generator, and renewable sources (optional)
Generator	3 PH of Power
Output Power	60 KW AC Power, 18 KW DC Power
Energy Storage	Battery systems with 36 batteries

Table 4. MHPS Characteristics

#### 1.2.5 Mobile Power Station BST – MT – HP, Black Sage Technologies

This product of Black Sage Technologies is based in a little trailer that has a solar panel, a wind turbine, and a rechargeable battery pack.



Figure 7. Black Sage Technologies, 2016, BST – MT – HP, Image

<b>Energy Sources</b>	Solar	315 W Monocrystalline
	Wind	400 W Wind Turbine
<b>Output Power</b>	1500W	
<b>Energy Storage</b>	Battery pack of 24V, 800Ah, 9.6KWh	
<b>Inverter</b>	1500W	
<b>Solar Controller Charge</b>	12V 15A MPPT	
<b>Dimensions</b>	Trailer's size: 3.96m x 1.27m x 1.78m	
<b>Price</b>	15,519.16 €	

Table 5. BST – MT – HP Characteristics

#### 1.2.6 Off – Grid Solar Trailer Power Systems, SunWize®

SunWize® is a North American firm that designs and installs power solutions. The firm has developed some Off – Grid Solar Trailer Power Systems, which characteristics are shown below (Table 6):

<b>Energy Source</b>	Solar
<b>Output Power</b>	1200W
<b>Energy Storage</b>	Rated Battery Capacity of 600 Ah
<b>Dimensions</b>	6400 x 2400 x 1680 mm

Table 6. Off - Grid Solar Trailer Power System Characteristics



Figure 8. SunWize, 2017, Off - Grid Solar System Closed, Render



Figure 9. SunWize, 2017, Off - Grid solar system Opened, Render

## 2 COMPONENTS

### 2.1 PV SOLAR PANELS

The photovoltaic solar panel is an interconnected assembly of solar cells packaged in a robust, weather-proof casing, which produces electric current from sunlight. These cells are made from semiconductor materials, which can produce the electricity through a process called the photovoltaic effect.

#### 2.1.1 Relationship among PV cell, module, and array

Before exposing some specific concepts about PV solar panels, it might be necessary to define the difference between the following concepts:

##### *Solar Cell*

It is the component that generates electricity from sunlight. It is made of semiconductor materials like silicon in which the PV effect occurs. Solar cells are interconnected in series and parallel electrical connections to produce desired voltages and currents.

##### *PV module*

A PV module is composed of PV cells which are interconnected together, grouped, laminated, and packaged between sheets of plastic and glass. The module has a frame (usually made from aluminum) that gives it rigidity and allows for ease of handling and installation. On the backs of the PV modules, there are junction boxes, where conductor connections are made to transfer power from the modules to loads.

##### *PV array*

A PV array is a set of PV modules connected in series and parallel to increase the total available power output, obtaining the needed voltage and current for a specific application.

#### 2.1.2 Solar Cell Technologies

Solar cells are mostly made from silicon as single-crystal, polycrystalline, or amorphous solids. Depending on the type the efficiency and the price changes.

##### *Monocrystalline silicon*

Cells are made from an ingot of a single crystal of silicon. Is the most efficient, with a typically range from about 15-20%. Modules made of this type of cell are the most mature on the market. Reliable manufacturers of this type of PV module offer live – guarantees of up to 20-25 years.



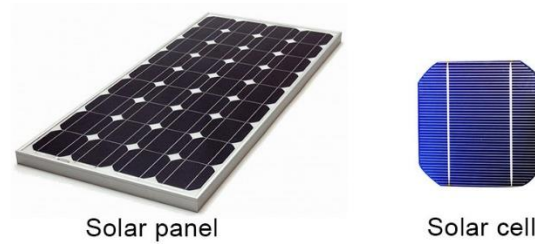


Figure 10. LED Watcher, 2017, Monocrystalline Solar Panel and Cell, Image.

#### **Polycrystalline silicon**

These cells are made up of various silicon crystals formed from an ingot. Their efficiency is slightly lower than monocrystalline cells, generally from 13 to 15%. Reliable manufacturers normally guarantee polycrystalline PV modules for 20 years.



Figure 11. LED Watcher, 2017, Polycrystalline Solar Panel and Cell, Image

#### **Amorphous silicon**

There is no geometric cell structure in this type. Commercial modules typically have an efficiency around 5-10%. Manufacturers use to guarantee this type of PV panels for 10 years. Amorphous PV cells have shorter lifetimes from accelerated cell degradation in sunlight. However, they are used for some electronic devices such as watches and calculators.

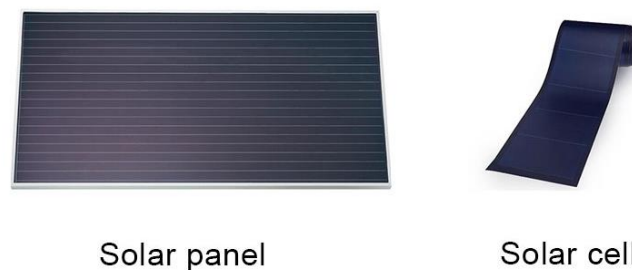


Figure 12. LED Watcher, 2017, Thin - Film Solar panel and cell, Image

### **2.1.3 PV Electrical Characteristics**

#### **Peak Watt**

PV modules are rated by their total output power, or peak Watts. A peak Watt is the amount of power output a PV module produce at a Standard Test Conditions (STC), which determine the following conditions:

- Solar irradiance of 1,000 W/m<sup>2</sup>.
- PV cell temperature of 25°C.
- Standardized solar spectrum referred to as an air mass 1.5 spectrum (AM=1.5).

### I-V curves

The I-V curve of a solar cell is shown in Figure 13, and represent the current – voltage relationship of a PV device. These curve plots are used to measure the electrical characteristics of a PV system.

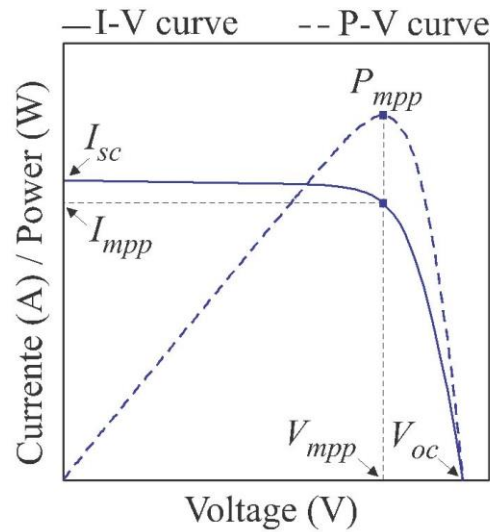


Figure 13. Identification of  $I_{sc}$ ,  $V_{oc}$ ,  $I_{mpp}$ ,  $V_{mpp}$  and  $P_{mpp}$  on the I-V and P-V curves.

Each I-V curve has a set of characteristic points that should be understood to appropriately install and troubleshoot PV power systems:

**Short-circuit current ( $I_{sc}$ ).** Is the maximum current generated by a cell or module and its produced at zero voltage when, an external circuit has no resistance. It is commonly used for all electrical ampacity design calculations.

**Open-circuit voltage ( $V_{oc}$ ).** Maximum voltage generated by a cell. It is measured when no external circuit is connected to the cell and so there is no current.

**Maximum power point ( $P_{mp}$ ).** The point in which the power delivered by the solar cell is maximum. It is the product of  $I_{mp}$  and  $V_{mp}$ . The maximum power point is the desired point of operation of any PV module.

**Maximum power operating current ( $I_{mp}$ ).** Current generated by a cell corresponding to the maximum power point.

**Rated maximum power voltage ( $V_{mp}$ ).** Voltage value in the maximum power point.

### Efficiency

Even though it has been shown that the type of cell technology affects directly on its efficiency, there are other parameters that also have an influence to the output power the PV module generates.

The datum of the PV panels is given in STC, so that means that has been considered an irradiance of  $1000\text{W/m}^2$ . But at it can be observed in the Figure 14, if the existent irradiance is lower also it is the current generated by solar cells.

The temperature has also a high effect in the electric parameters of the solar cell, and so in its efficiency. When the operating temperature of a cell increases,  $I_{sc}$  increases slightly,  $V_{oc}$  decreases more significantly, and  $P_{mp}$  also decreases.

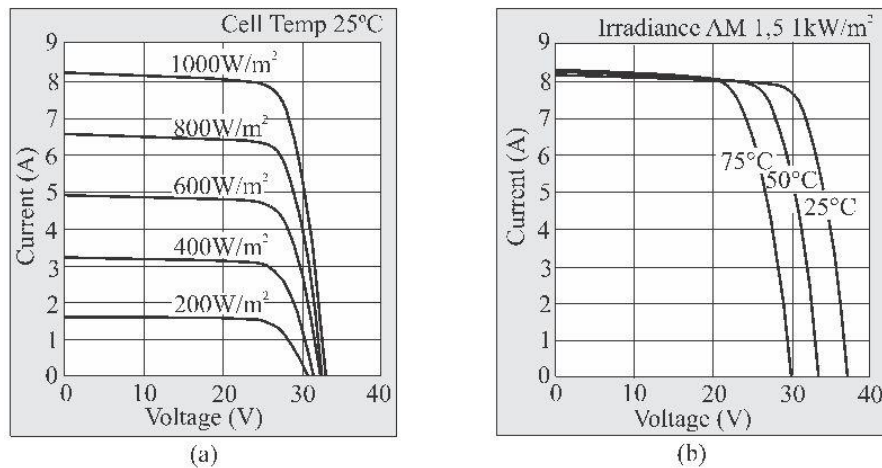


Figure 14. I-V curve from Kyocera KC200GT PV module: (a) under constant temperature and (b) under constant irradiance.

Temperature coefficients are set to determine the variation of the electric parameters due to temperature variation. For silicon, solar cells, these coefficients are:

- I<sub>sc</sub> temperature coefficient ( $\alpha$ )= 0.1%/°C
- V<sub>oc</sub> temperature coefficient ( $\beta$ )= -2 mV/°C
- P<sub>mp</sub> temperature coefficient ( $\gamma$ )= -0.5 %/°C

Also, exists a strong relationship between the angle of incidence of light and the PV panel's output power. Thus, the orientation of PV panels is important, and it must be determined in such a way that the sunlight has a perpendicular impact into the panel, as much as possible. There exist some structures that follow the sun automatically so that to make sure the PV panel is always in the best position.

## 2.2 BATTERIES

### 2.2.1 Introduction

A battery is a device that converts chemical energy into electrical energy. The battery system play an important role in MREU as it is the gadget that stores the energy produced by the power sources.

Batteries are normally classified into two wide categories, primary and secondary batteries. The first ones are intended to be used only once, and discarded without being charged again, whereas the secondary batteries are rechargeable, so they are intended to be recharged many times and therefore have significantly longer lifetimes than primary batteries.

Only the secondary batteries are going to be described in more depth since they are the ones used in mobile unit power systems.

### 2.2.2 Batteries parameters definitions

#### Open circuit voltage (V)

The open circuit voltage (OCV) is the voltage across the battery terminals when it is at rest (i.e. the battery is not being charged or discharged).

#### Voltage (V)

Batteries are marked with nominal voltage. This voltage is the one in which the system is going to work. In a PV system, its value is normally 12V, 24V or 48V. However, the open circuit voltage

on a fully charged battery is 5 – 7% higher. The closed-circuit voltage (CCV) is the operating voltage.

*Cut-off Voltage (V)*

The minimum allowable voltage, which generally defines the “empty” state of the battery.

*Terminal voltage (V)*

Voltage between the battery terminals with load applied. Terminal Voltage varies with SOC and discharge/charge current.

*Internal Resistance ( $\Omega$ )*

Batteries have an internal resistance, which generally is different for charging and discharging and depend on battery state of charge. As internal resistance increases, the battery efficiency decreases.

*Capacity or Nominal Capacity (Ah)*

The capacity of a battery represents the discharge current a battery can deliver over time, and it is described in ampere-hours (Ah). It is calculated by multiplying the discharge current (A) by the discharge time (h), and its value decreases with increasing C-rate.

*C-rate*

In describing batteries, discharge current is often expressed as a C-rate to normalize against battery capacity, which is often very different between batteries. A C-rate specifies the speed a battery is charged or discharged. For example, A 1C rate means that a fully charged battery rated at 1Ah should provide 1 A for one hour. The same battery discharging at 0.5C should provide 500A, for two hours. A C-rate of 0.5C can also be written as C/2.

*Energy or Nominal Energy (Wh)*

The total Watt-hours represent the nominal energy of a battery available from 100 percent state-of-charge to the cut-off voltage, when the battery is discharged at a certain discharge current (specified as a C-rate). Like capacity, energy decreases with increasing C-rate.

*Specific Energy (Wh/kg), Energy Density (Wh/L), Specific Power (W/Kg) and Power density (W/L)*

Specific energy or gravimetric energy density defines battery capacity in weight (Wh/Kg). Energy density or volumetric energy density reflects volume in liters (Vh/L). Specific Power is the maximum available power per unit mass (W/Kg), while power Density is the maximum available power per unit volume (W/L).

*State of Charge (SOC) (%)*

SOC express the present battery capacity as a percentage of the maximum capacity.

*Depth of Discharge (DOD) (%)*

The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity.

*Cycle Life*

The cycle life is the total number of discharge-charge cycles the battery can experience. It is estimated for specific charge and discharge conditions. The cycle life value depends on the DOD, so that the higher the DOD, the lower the cycle life. Nevertheless, the actual operating life of the battery is affected by the rate of cycles and some conditions such as temperature and humidity.

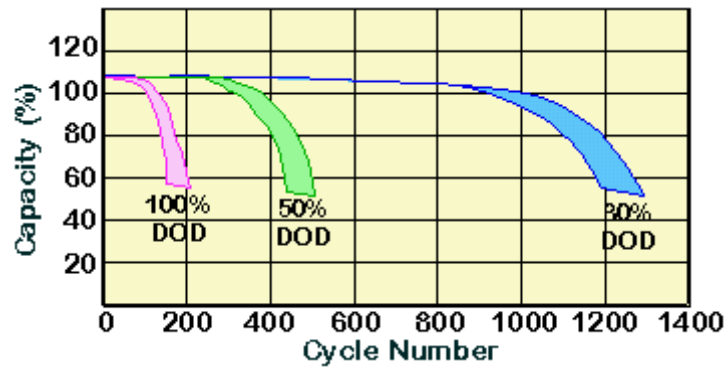


Figure 15. Depth of Discharge lifetime for a shallow cycle battery graph from pveducation.org

#### Maximum Continuous Discharge Current

The maximum current at which the battery can be discharged continuously, to prevent excessive discharge rates that would damage the battery or reduce its capacity. The manufacturer usually defines this parameter.

#### Maximum 30-sec Discharge Pulse Current

The maximum current at which the battery can be discharged for pulses of up to 30 seconds, to prevent excessive discharge rates that would damage the battery or reduce its capacity. The manufacturer usually defines this parameter.

#### Charge Voltage

The voltage that the battery is charged to when charged to full capacity.

#### Float Voltage

The voltage that the battery must be charged after being charged to 100 % SOC to maintain that capacity by compensating for self-discharge of the battery.

#### (Recommended) Charge Current

The ideal current at which the battery is initially charged (to roughly 70 % SOC) under constant charging before transitioning into constant voltage charging.

### 2.2.3 Rechargeable Batteries Technologies

#### Lead Acid

This is the oldest type of rechargeable batteries in the market. Lead acid is rugged and economically priced, but it has a low specific energy and limited cycle count. There are different types of Lead Acid batteries, the flooded type, sealed lead acid, valve-regulated lead acid (VRLA) and absorbent glass mat (AGM). The first ones need watering.

#### Advantages

- Low cost
- Reliable
- Simple to manufacture
- Low self-discharge
- Can deliver very high currents
- Good low and high temperature performance.

#### Limitations

- Low specific energy – very heavy
- Slow charge, fully saturated charge takes 14-16 hours.
- Must be stored in charged condition to prevent sulfation<sup>1</sup>
- Limited cycle life; repeated deep cycling reduces battery life.
- Flooded version requires watering.
- Contain toxic chemicals.

Main characteristics	Applications
<ul style="list-style-type: none"> <li>- Cycle life: 300-500 cycles</li> <li>- Fully charge time: 14-16 hours.</li> <li>- Discharge: 5h (0.2C)/ 20h (0.05C)</li> <li>- Cost: low</li> </ul>	<ul style="list-style-type: none"> <li>- Automotive and traction applications: wheelchairs, golf cars, etc.</li> <li>- Emergency lighting and uninterruptible power supply (UPS).</li> <li>- Submarines.</li> <li>- High current drain applications.</li> </ul>

Table 7. Lead Acid Characteristics

1. Internal resistance increase of the battery due to the formation of large lead sulfate crystals, which are not readily reconverted back to lead, lead dioxide and sulfuric acid during recharging.



Figure 16. Lead acid batteries, [www.directindustry.com](http://www.directindustry.com)

#### Nickel-cadmium (NiCd)

The NiCd batteries are ones of the most rugged and enduring batteries, but they need proper care to attain longevity. They are used when long service life, high discharge current and extreme temperatures are required. Its chemistry is the only one that allows ultra-fast charging with minimal stress.

Advantages	Limitations
<ul style="list-style-type: none"> <li>- Rugged, high cycle count with proper maintenance.</li> <li>- High rate charge/discharge.</li> <li>- Wide temperature range.</li> <li>- Can be stored in a charged or discharged state without damage.</li> <li>- NiCd is the lowest in terms of cost per cycle.</li> <li>- Flat discharge characteristic.</li> </ul>	<ul style="list-style-type: none"> <li>- Suffers from memory effect<sup>2</sup></li> <li>- High self-discharge; needs recharging after storage.</li> <li>- Cadmium is a toxic metal, cannot be disposed of in landfills.</li> <li>- Relatively low specific energy compared with newer systems.</li> </ul>
Main characteristics	Applications
<ul style="list-style-type: none"> <li>- Cycle life: 500 cycles</li> <li>- Fully charge time: typically, 2 hours.</li> <li>- Cost: relatively inexpensive for low power applications but between three and four times more expensive than lead-acid for the same capacity.</li> </ul>	<ul style="list-style-type: none"> <li>- Motorized equipment</li> <li>- Two-way radios.</li> <li>- Medical equipment.</li> <li>- UPS</li> <li>- Toys</li> </ul>

Table 8. Nickel - Cadmium Characteristics

2. The memory effect consists on losing the maximum energy capacity due to repeatedly being recharged after being only partially discharged. A battery with memory effect needs periodic full discharges and can be rejuvenated.

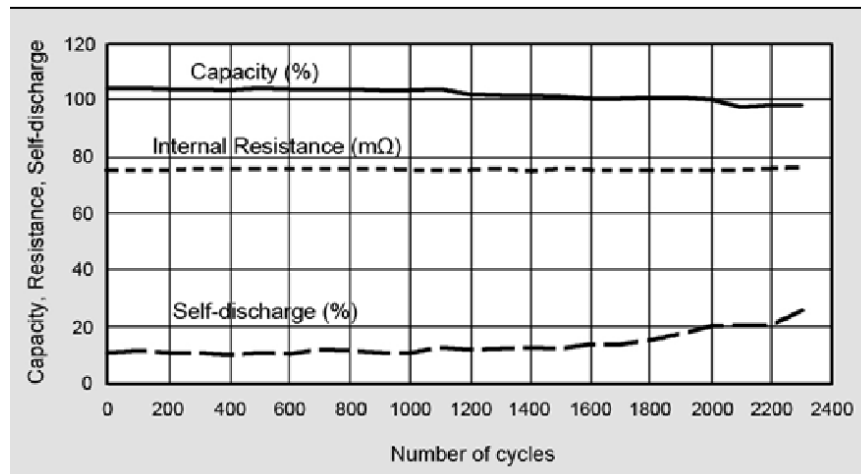


Figure 17. Performance of standard NiCd (7.2V - 900mAh) from [www.batteryuniversity.com](http://www.batteryuniversity.com)



Figure 18. Nickel - Cadmium batteries, from [www.changhongbatteries.com](http://www.changhongbatteries.com)

#### Nickel-metal hydride (NiMH)

This type came out after some years doing more research. NiMH has replaced NiCd in most applications due to its higher capacity. However, NiMH batteries have also some drawbacks. The battery is more delicate and trickier to charge than NiCd.

#### Advantages

- High energy density (Wh/Kg)
- Low internal impedance
- Can be deep cycled
- Tolerant to over-charge and over-discharge conditions.
- Flat discharge characteristic
- Wide operating temperature range
- Environmentally friendly; contains only mild toxins.

#### Limitations

- High self-discharge rate (20% self-discharge in the first 24 hours after charge, and 10% per month thereafter)
- Deteriorates after a long-time storage

### Main characteristics

- Cycle life: 3,000 cycles
- Fully charge time: typically, 2 hours.
- Cost: little lower than NiCd batteries.

### Applications

- Low cost consumer applications
- Portable equipment
- Medical instruments and equipment
- Automotive batteries and electrical vehicles
- High power static applications (Telecom, UPS and smart grid).

Table 9. Nickel - metal hydride Characteristics

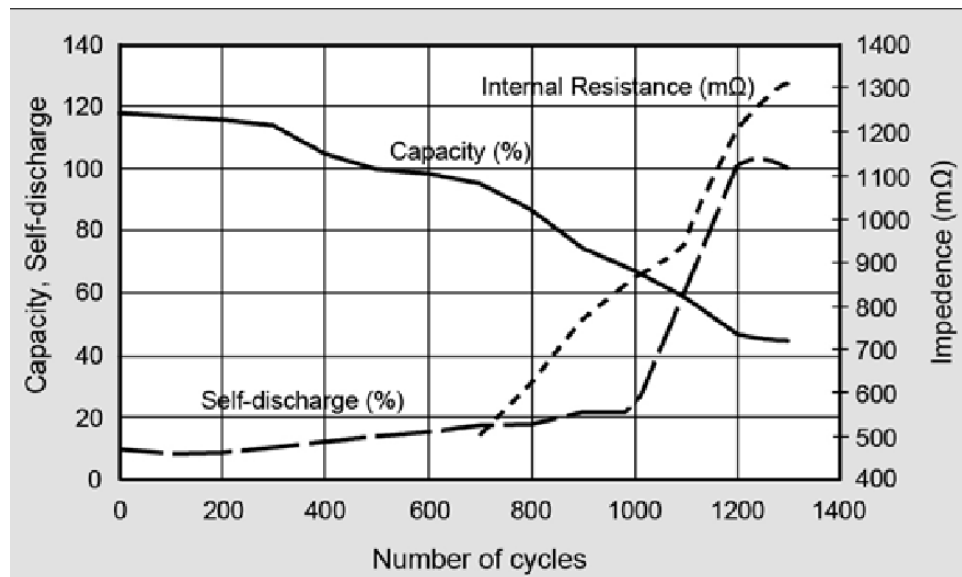


Figure 19. Performance of NiMH (6V - 95mAh) - [www.batteryuniversity.com](http://www.batteryuniversity.com)

### Nickel-zinc (NiZn)

Low cost, high power output and good temperature operating range make this chemistry attractive. It is like NiCd in the chemistry, but it differs in voltage. While NiCd provides 1.20V/cell, NiZn has 1.65V/cell.

### Advantages

- High rate capacity (25C)
- Good cycle life
- Fast recharge capability
- Can be deep cycled
- Uses low cost benign materials

### Limitations

- Low energy density
- High self-discharge rate

### Main characteristics

- Cycle life: 200-300 cycles
- Fully charge time: typically, 2 hours.
- Cost: low

### Applications

- Traction applications
- Electric bicycles
- Scooters
- Lawnmowers

Table 10. Nickel - Zinc Characteristics





Figure 20. Nickel metal hydride cell - [www.rechargebatteries.org](http://www.rechargebatteries.org)

#### Lithium-ion (Li-ion)

Li-ion batteries are being used increasingly. It is a low-maintenance battery, with no memory effect and low self-discharge. Its nominal cell voltage is of 3.6 V, so that makes these batteries very suitable for powering electronic devices such as mobile phones, tablets, and digital cameras.

#### Advantages

- High energy and power density.
- High cell voltage of 3.6V
- Low weight
- Long cycle and extend shelf-life; maintenance-free
- Low self-discharge rate
- No memory effects
- Reasonably short charge times

#### Limitations

- Internal impedance higher than equivalent NiCd
- Requires protection circuit to prevent thermal runaway if stressed.
- Degrades at high temperatures
- Capacity loss or thermal runaway when overcharged.

#### Main characteristics

- Cycle life: 1,000-3,000 cycles
- Fully charge time: typically, 2 hours.
- Cost: Although the prices at the beginning were very expensive, the price of lithium cells is falling as the technology gains more acceptances and they are getting reasonable values.

#### Applications

- A wide range of consumer portable, medical, and communication products.
- Traction application especially different types of electric vehicles.
- Standby power.

Table 11. Lithium - ion Characteristics

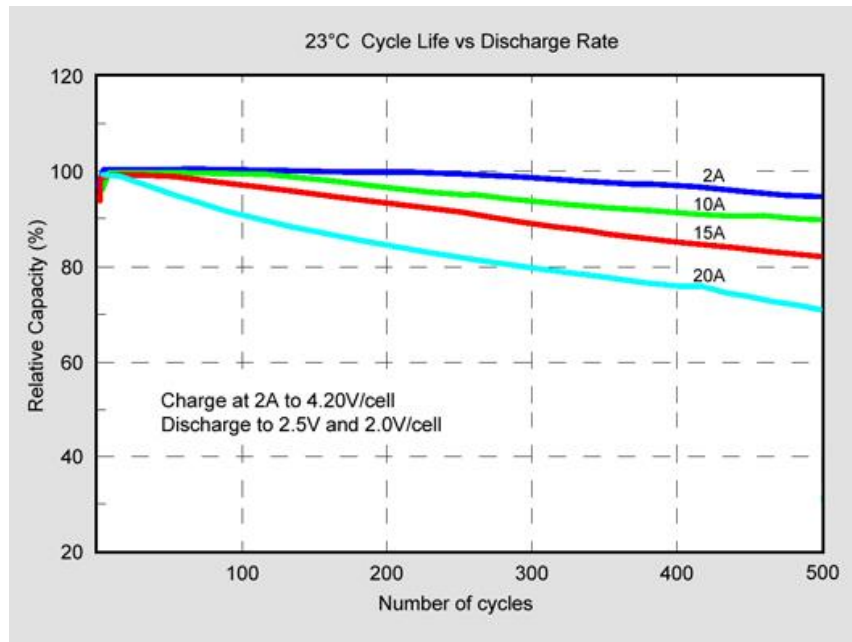


Figure 21. Cycle Characteristics of IHR18650C by E-One Moli (3.6V - 2,000mAh), [www.batteryuniversity.com](http://www.batteryuniversity.com)



Figure 22. LED Watcher, Li - on batteries, Image

## 2.3 INVERTER

An inverter is a gadget that can transform a DC input to an AC output. The 'inversion' goes from a constant value to bipolar waveform (can be positive or negative). In a solar system are used to block the power system.

To choose the right inverter, the user should consider some features such as the output power, input voltage, output waveform and voltage.

### 2.3.1 Defining parameters

#### *Waveform*

Usually, sine-waves are preferred. Square – waves contains a sine – wave and other harmonics of the same frequency that cause additional losses like power dissipation and electrical noise. Both consequences have an important affection on the final efficiency of the inverter.

#### *Voltage*

It's important to consider that the inverter input battery voltage should match the storage batteries.

When the batteries are extremely discharged, the inverter detects a cut – out voltage and turns itself off to protect both battery and inverter. A typical value for under – voltage shutdown is between 10 and 12 V approximately.

#### *Power*

As usually, it's defined in Watts (W) or kilowatts (kW) with two types of ratings: continuous and peak. The peak rating it's important for starting loads or motors. Its value can't be hold for more than one to ten seconds because it would cause and overheat of the system and a later shutdown.

Normally, each inverter has a LED graph system to show how many watts are being output from the inverter.

#### *Efficiency*

Switching inverters have efficiencies in the range of 80 – 90%. A part from the general parameters, there is another one that has affection on the inverter's efficiency: Internal power used. It increases proportionally to the power ratings. However, this waste can be minimized by choosing a not oversized inverter. For instance, if the output power is 300 W, choosing an inverter of 500 W or even 750 W it is right. If the 750 W unit draws more than 50% more current than the lighter one, consider choosing he unit of 500 W.

To not to be wrong, it's important to add the power loss of the inverter in the calculations to obtain the correct results.

### 2.3.2 Examples

Victron Energy is a European company that designs and sells inverters among other power conversion devices such as chargers, combiners, or isolators.

#### *Phoenix Inverter 3000 VA – 5000 VA*

The inverter shown in Figure 23 works with 12 / 24 / 48 V. It's a pure sine wave output, high peak power and high efficiency. Also combines high and medium frequency technologies giving the best of both.



Figure 23. Victron Energy, 2016, Phoenix Inverter 3-5kVA, Image.

This product is suitable for the widest range of applications. The result of employing hybrid High Frequency technology is a top – quality product with compact dimensions, high quality, a problem free with any load. To reach higher power (p.e 24kW/30kVA), it's possible to use up to 6 Phoenix Inverters in parallel. They also can operate both in one and three – phase configurations.

Input voltage range (V DC)	9.5 – 17	19 – 33	38 – 66
Output	230 VAC $\pm 2\%$ – Frequency: 50 $\pm 1\%$		
Peak Power (W)	2,400 – 3,000	4,000 – 6,000	10,000
Maximum efficiency (%)	92 – 94	94	94 - 95
Material	Aluminum		
Weight (kg)	10	12 – 18	30
Dimensions (mm)	375x214x110	520x255x125 – 362x258x218	444x328x240
Other Characteristics	Protection against short circuit and overload		
	Protection against extreme voltage (very high or very low)		
	Protection against high temperatures		
	Protection against 230 VAC on inverter output		

Table 12. Phoenix Inverter 3 -5 kVA Characteristics

Figure 24 describes the electric circuit this device should follow. There's also a *Phoenix battery charger*. Its function it's to regulate the circuits as well as make it work.

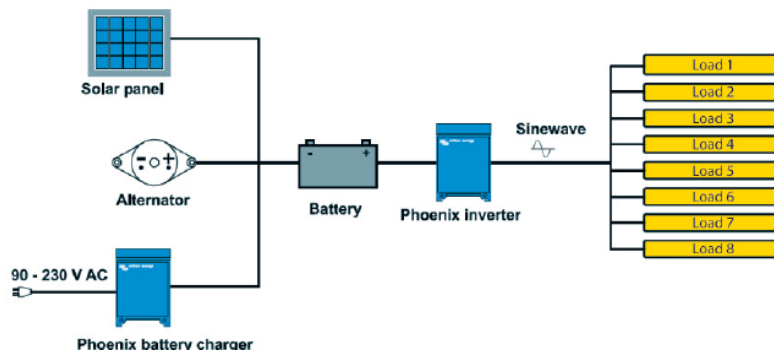


Figure 24. Victron Energy, 2017, Phoenix Inverter 3 – 5kVA, Circuit Diagram

**Phoenix Inverter Compact 1200 VA – 3000 VA**

This device is similar to the previous one, just with lower power output. In Table 13 its characteristics can be founded. Can be connected to 12 /24 V. Its circuit it's described above – Figure 24.

Input voltage range (V DC)	9.5 – 17	19 – 33
Output	120 VAC $\pm 2\%$ – Frequency: 60 $\pm 1\%$	
Peak Power (W)	6000	
Maximum efficiency (%)	93	94
Material	Aluminum	
Weight (kg)	18	
Dimensions (mm)	362x258x218	
Other Characteristics	Protection against short circuit and overload	
	Protection against extreme voltage (very high or very low)	
	Protection against high temperatures	
	Protection against 230 VAC on inverter output	

Table 13. Phoenix Inverter Compact 1.2 - 3kVA Characteristics



Figure 25. Victron Energy, 2016, Phoenix Inverter 1.2 – 2 kVA, Image

## 2.4 WIND TURBINE

Wind energy plays a key role in the renewable energy field. There are many types of wind turbines but all do the same function; take profit from the energy of the wind and convert it into electricity. Wind turbines are very used and it has been proved that they work well. However, for off-grid electrification a combination of photovoltaic and wind energy technologies may be the perfect option.

### 2.4.1 Wind Turbine technology

There are two classes of wind turbines depending on the position of the motor axis: vertical-axis, and horizontal-axis. The difference between both lies in their rotors spin orientation.

#### *Vertical – axis wind turbines (VAWTs)*

The principal advantage of VAWTs is that they are omnidirectional; they accept the wind from any direction. Thus, its design simpler. Another advantage is that the vertical axis of rotation permits mounting the generator and transmission devices at ground level.

However, these advantages are counteracted by a reduced energy capture since the rotor intercepts winds having less energy. Furthermore, despite having the generator and transmission at ground level, maintenance is not simple since it usually requires rotor removal.

By these reasons, the use of vertical-axis wind turbines has considerably declined during the last decades

#### *Horizontal Axis wind turbines*

Nowadays, the most of all commercial wind turbines are horizontal-axis ones. This type has the rotor located at the top of a tower, and also a nacelle with the gearbox and the generator assembled inside it lie on the top.

Unlike VAWTs, horizontal-axis wind machines must change direction with the wind. Thus, they must have some means for orientating the rotor with respect to the wind in order to capture as much energy as possible.

On smaller wind turbines, the task of orientating the rotor consist only in a simple tail vane, while the ones with higher power use to have a complicated yaw mechanism. These mechanisms can be classified as *Passive Yaw* and *Active Yaw*. The first ones use the force of wind itself to orient the rotor upwind of the tower. So, they passively change the orientation of the wind turbine with respect to changes in wind direction without the use of human or electrical power. The Active Yaw is used for bigger-size turbines and consist in a more sophisticated mechanism with motors to keep the rotor upwind of the tower.

### 2.4.2 Wind energy conversion

The power of the wind passing an area  $A$  with a wind velocity  $v_1$  is defined by the following expression:

$$P_w = \frac{1}{2} \rho A v_1^3 \text{ (eq 1)}$$

Where  $\rho$  is the specific air mass which depends on air pressure and moisture; for practical calculations, it may be assumed  $\rho = 1.2 \text{ Kg/m}^3$ .  $A$  is the circular swept area of the wind turbine.

The useful mechanical power obtained is expressed by means of the power coefficient  $c_p$ :

$$P = c_p \frac{\rho}{2} A v_1^3 \text{ (eq 2)}$$

The value of  $c_p$  normally is around 0.4 – 0.5 at maximum, due to losses.

An important parameter of wind rotors is the tip-speed ratio  $\lambda$ , which is the ratio of the circumferential velocity of the blade tips and the wind speed:

$$\lambda = \frac{u}{v_1} \text{ (eq 3)}$$

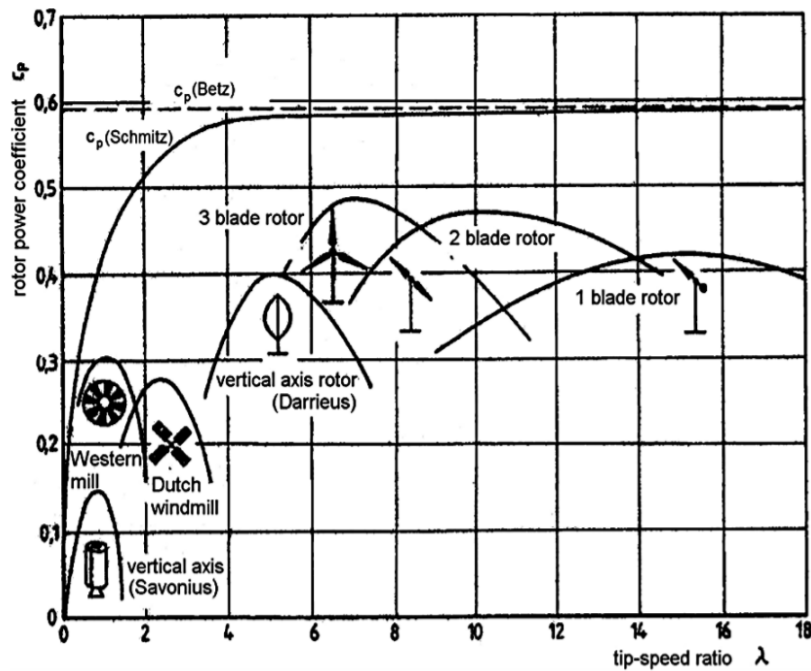


Figure 26. STIEBLER, M. 2008, *Wind Energy Systems for Electric Power Generation*, Diagram

#### 2.4.3 Parts of a turbine

In general, wind turbines have the following components:

1. Rotor: It is the component through which energy of the wind is converted in a rotatory movement.
2. Electric generator. Converts the rotatory movement into electricity.
3. Passive or active electronic components for feeding electricity into a battery bank or public grid.
4. Orientation mechanism. By this mechanism, the rotor can always face the wind.
5. Gearbox. Changes the rotation velocity in order to achieve the needed velocity for the generator.

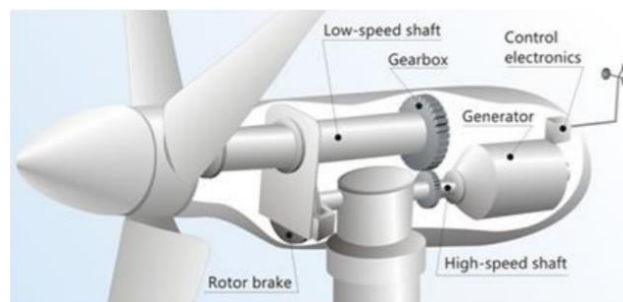


Figure 27. CARRIVEAU Rupp (In Tech), 2012 *Wind Turbine scheme*, 3D Drawing

#### 2.4.4 Control and Power Limitation

As wind power, may be very changeable, it is need a system that controls and limit the speed of the turbine and the generated power to not damage the turbine and the other components. There are two systems to do these tasks:

##### *Pitching Mechanism*

Consist in variate the blade angle, to control the rotor torque and power from the wind side, and at the same time provide power and speed limitation at high wind velocities.

### Stall Mechanism

By this mechanism, power above a certain rotation speed is limited for reasons of safety and to avoid overload. Different methods can accomplish this, one of them consists in turning the rotor out of the wind direction.

### Other Power Limitation Concepts

Small wind turbines in the kW power-range sometimes use other concepts such as passive pitch control, or a passive mechanism tilting the turbine in dependence of wind exerted axial force and decreasing the swept area from circular to elliptic.

#### 2.4.5 System Power Characteristics

The most essential information for a wind energy system capability is the power curve, which is a measured curve of the delivered power over wind speed. These curves together with the knowledge of average wind velocity and distribution properties are indispensable for predicting the annual energy yield.

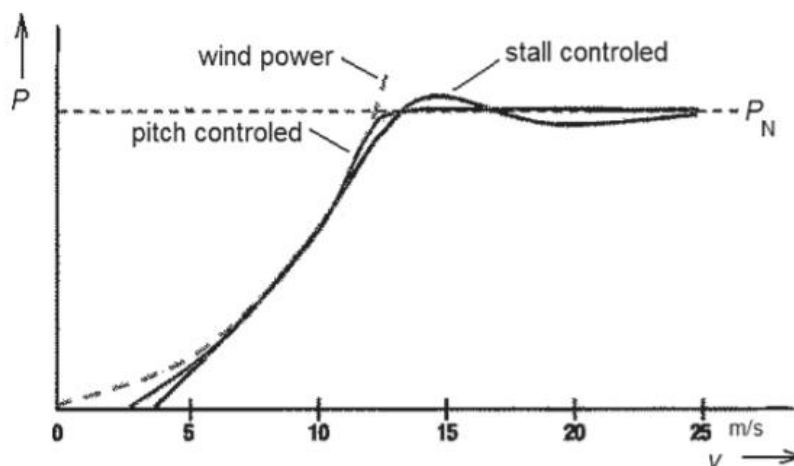


Figure 28. STIEBLER Manfred, 2008 Curves for a pitch controlled and stall – controlled systems, Diagram.

It can be observed in the previous curve that either one of the control systems effects power limitation at wind speeds above the rated value:

- Pitch control, where the power is controlled to rated power above a preset threshold wind speed (mostly the rated speed).
- Stall control, where a transient phenomenon with power overshoot is observed for winds speed above rated value.

The following characteristic wind velocity values are specified with the design for each wind turbine:

- Average velocity  $v_{av}$ .
- Optimum velocity  $v_{av}$ , which is the velocity at the best point  $\lambda_{opt}$
- Velocity at maximum energy yield.
- Rated wind speed, which is the value of velocity at which the power limitation begins to work.
- Cut-in velocity, at which the turbine starts to supply power.
- Cut-off velocity, at which the turbine is brought to standstill for safety reasons.
- Survival-velocity, maximum velocity in order not to break down.

#### 2.4.6 Wind Turbine Generators

The generator is one of the main components in the wind turbine, responsible for the conversion of mechanical power from the rotor (prime mover) into electricity. There are three main types of



generators: direct current (DC), altering current (AC) synchronous and AC asynchronous generators.

Generators are rated in terms of the maximum current they can supply at a specified voltage and, for AC generators, at a specific frequency.

Despite there is no consensus among academics and industry on which is the best wind turbine generator technology, each type has its characteristics that make it suitable or not depending on the application.

#### *DC Generator Technologies*

The power produced by a generator depends on the diameter and length of the wires used in the armature, the strength of the magnetic field and the rate of motion between them. So, if the wind speed increases, the current generated will be greater too. To prevent generator overheating generators usually employ a means for limiting current to a safe maximum.

An example of the DC wind generator system is illustrated in Figure 29. It consists of a wind turbine, a DC generator, an insulated gate bipolar transistor (IGBT) inverter, a controller, a transformer, and a power grid.

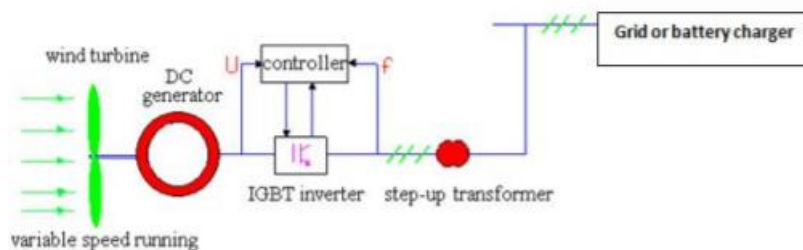


Figure 29. CARRIVEAU Rupp, 2012, DC Generation system, Diagram

DC wind turbines generators are unusual in wind turbine applications except in low power demand situations, where the load is physically close to the wind turbine, in heating applications or in battery charging.

#### *AC Synchronous Generator Technologies*

As the name implies, these generators create alternating current when the wind turbine drives the rotor. For fixed speed, synchronous generators, the rotor speed must be kept at exactly the synchronous speed, otherwise the synchronism will be lost. When wind speed rises, the turbine spins faster, increasing frequency. Most of AC generators used in wind systems produce three-phase AC, because its efficiency is higher.

#### *AC Asynchronous (Induction) Generators*

Induction generators create electricity from a rotating magnetic field established in the airgap when supplied with three-phase AC power to the stator. In general, asynchronous machines are simple, reliable, inexpensive, and well developed. However, they draw reactive power from the grid and thus some form of reactive power compensation is needed, such as capacitors or power converters.

There are two types of these generators: squirrel cage induction generators and wound rotor induction generators. The first ones have proved extremely popular for wind turbines because they are widely available in a range of sizes, and their interconnection with the utility is straightforward.

The wound rotor induction generator is more expensive, but it facilitates operating the wind turbine at variable speed. However, it requires an AC-DC-AC inverter for producing utility compatible electricity.

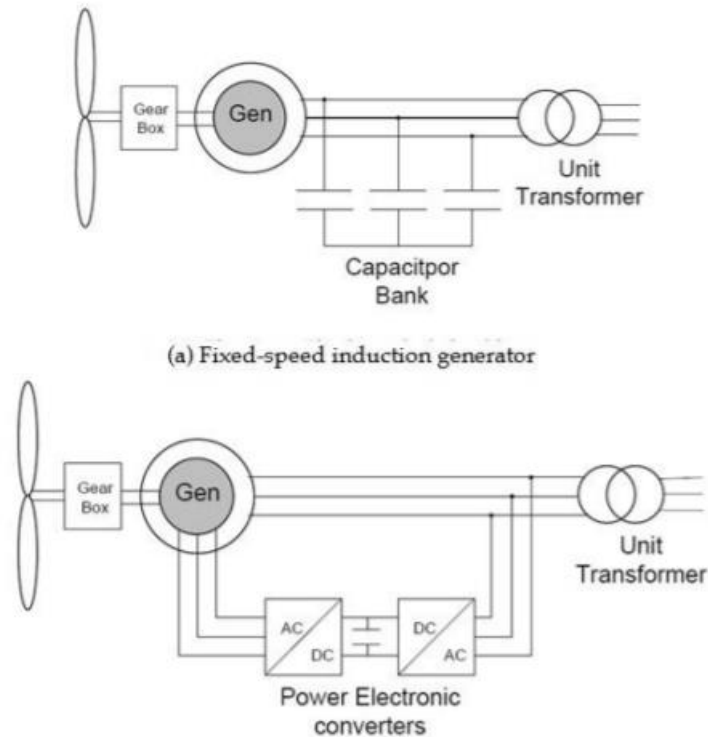


Figure 30. CARRIVEAU Rup. (In Tech), 2012, Two induction generator systems, schematic drawing.

#### 2.4.7 Small wind turbines examples

Things we should know to choose a wind turbine – parameters that appear in wind turbines' datasheets.

##### *Missouri Rebel Freedom 5 Blade Wind Turbine*

Missouri is a company from USA which has developed different models of small wind turbines. This one has the following specifications:

<b>Output power</b>	1600 W
<b>Generator</b>	Permanent Magnet Generator (PMG), three-phase power generation. 3 phase bridge rectifier for converting to DC output.
<b>Available Voltage</b>	12V, 24V or 48V
<b>Number of blades</b>	5
<b>Blade material</b>	Carbon fiber
<b>Price</b>	314 €

Table 14. Missouri Rebel Freedom 5 Blade Wind turbine characteristics



Figure 31. Missouri Wind and Solar Wind Turbine ([www.mwands.com](http://www.mwands.com))

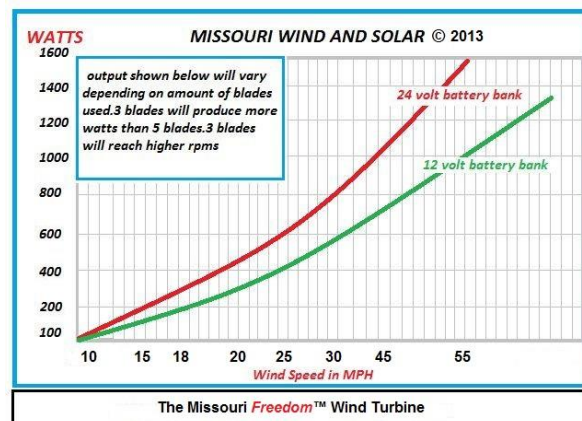


Figure 32. Wattages derived at on a 19m wind turbine tower with no obstructions ([www.mwands.com](http://www.mwands.com))

#### Bornay Wind Turbines

Bornay is a company founded in 1970 in Spain, but today it is working in about 50 countries. It has developed three general models of wind turbines, one of them is Wind turbine Bee 800, which characteristics are explained below:

<b>Output power</b>	800 W
<b>Generator</b>	Permanent Magnet Generator (PMG), three-phase power generation.
<b>Available Voltage</b>	12V, 24V or 48V
<b>Number of blades</b>	5
<b>Diameter</b>	1.75 m
<b>Blade material</b>	Injected nylon
<b>Performance, wind speed</b>	<ul style="list-style-type: none"> <li>- For turn on: 3.5 m/s</li> <li>- For nominal power: 12 m/s</li> <li>- For survival: 60m/s</li> </ul>

Table 15. Bornay Wind Turbines Characteristics

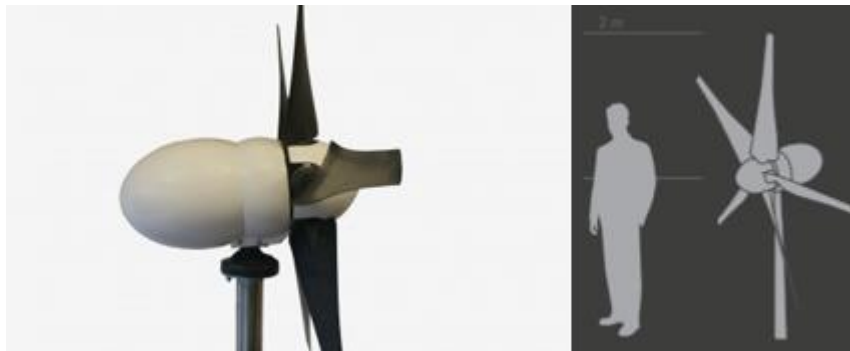


Figure 34. Wind Turbine Bee 800, [www.bornay.com](http://www.bornay.com)

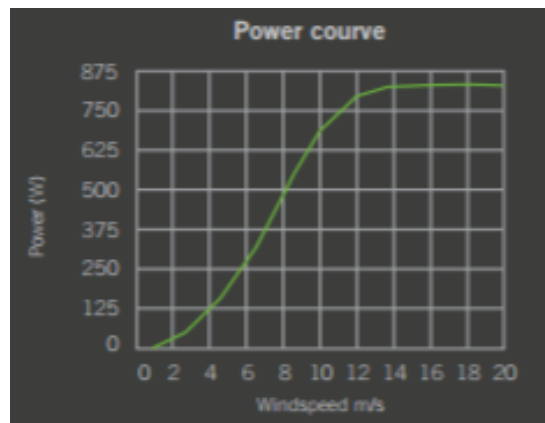


Figure 33. Bornay, PV - Curve of Wind Turbine Bee 800 ([www.bornay.com](http://www.bornay.com))

#### *The Wind leaf wind turbine, by Wind challenge*

*Wind challenge* is a company based in Rotterdam, Netherlands, which designs and produces energy solutions based on wind energy. The Wind leaf is a small wind turbine they have developed; which characteristics are shown below:

<b>Output power</b>	700 W
<b>Generator</b>	Permanent Magnet Generator (PMG).
<b>Available Voltage</b>	12V, 24V or 48V
<b>Number of blades</b>	3
<b>Blade material</b>	UV protected reinforced thermoplastic
<b>Diameter</b>	1.7 m
<b>Performance, wind speed</b>	<ul style="list-style-type: none"> <li>- Start-up wind speed: 1.5 m/s</li> <li>- Rated wind speed: 9.5 m/s</li> <li>- Cut-out wind speed: 21 m/s</li> </ul>
<b>Others</b>	Pitching blades
<b>Price</b>	3,280 €

Table 16. Wind leaf wind turbine Characteristics

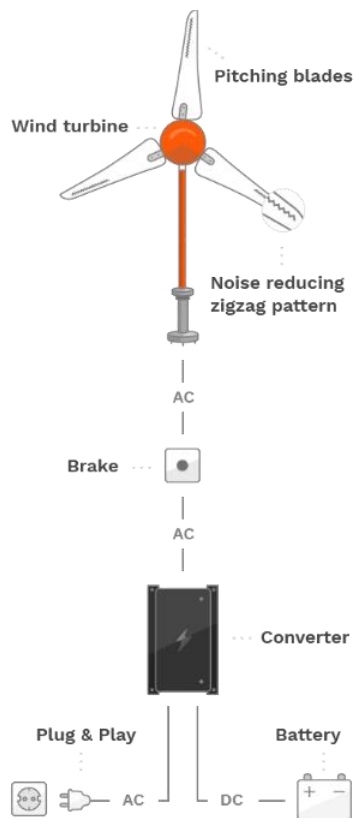


Figure 35. Scheme of the different components using the Wind leaf



Figure 36. Wind Challenge, The Wind leaf Turbine

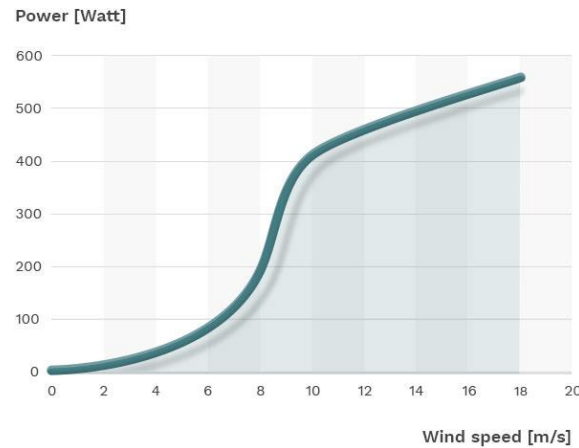


Figure 37. Wind Challenge, PV - curve of the Wind leaf Turbine

## 2.5 GENERATOR

The generator it's the one responsible of converting the mechanical energy into electric energy (in DC or AC monophasic and AC three – phasic). Generators can be classified in different ways: per how their field flux is produced or the type of combustible used. The electric energy then produced can be used for power transmission to commercial, industrial, or even domestic level. The frequency usually used is 50 Hz.

The generator can be divided in the stator and the rotor. The first one comprises the stationary magnetic poles, while the second one has the rotating armature. The system works under faraday's law of Electro – Magnetic induction.

Figure 38. Electrical Engineering Community, 2013, Flux generation by Faraday's Law, Sketch. Shows this operation. When the conductor rotates I the magnetic field, it creates a voltage difference between the two ends, this way the flux changes and an EMF is created and hence, the current flows.

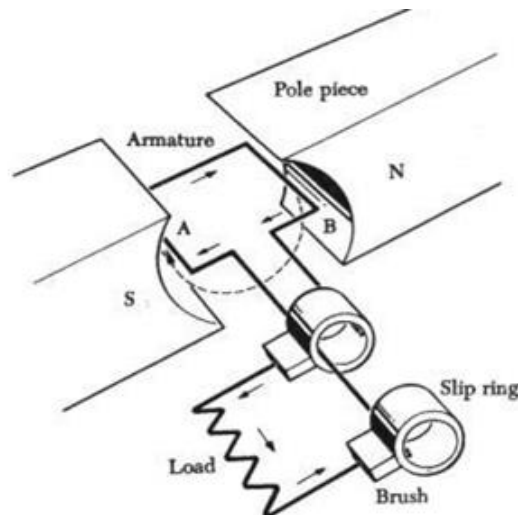


Figure 38. Electrical Engineering Community, 2013, Flux generation by Faraday's Law, Sketch.

### 2.5.1 Classification based on field flux production

#### *Separately Excited Generator*

In this case, the field flux is derived from a separate power source independent of the generator. Figure 39 shows the equivalent circuit.

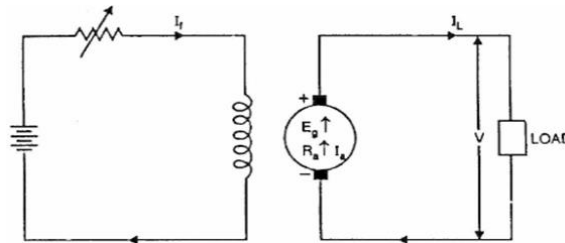


Figure 39. Electrical Engineering Community, 2013, Separately Excited Generator Circuit, Sketch

#### *Shunt Generator*

In the Shunt Generator, the field flux is produced by connecting the field circuit directly across the terminals of the Generator. Figure 40 shows the equivalent circuit of the Shunt Generator.

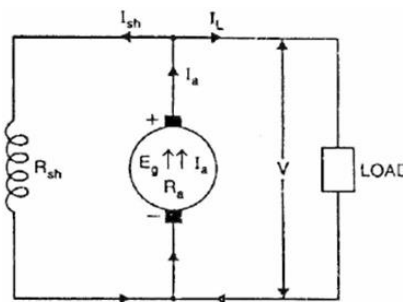


Figure 40. Electrical Engineering Community, 2013, Shunt Generator Circuit, sketch.

#### *Series Generator*

In this third type of Generators, the field flux is produced by connecting the field circuit in series with the armature of the generator. See the equivalent circuit shown below (Figure 41).

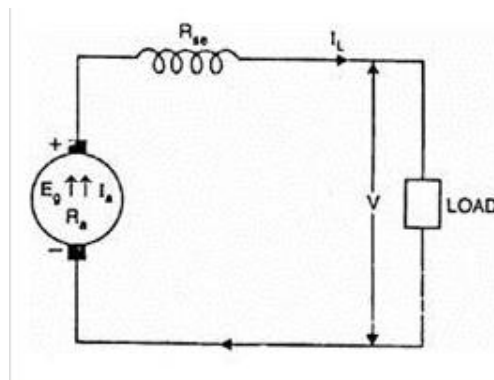


Figure 41. Electrical Engineering Community, 2013, Series Generator Circuit, Sketch.

#### *Commutatively Compound Generator*

This type is the one in which there are both series and shunt fields, connected so that the magneto – motive forces from both sources add up. It can be Long Shunt Compound or Short Shunt Compound. The equivalent circuit it's the one described on Figure 42.

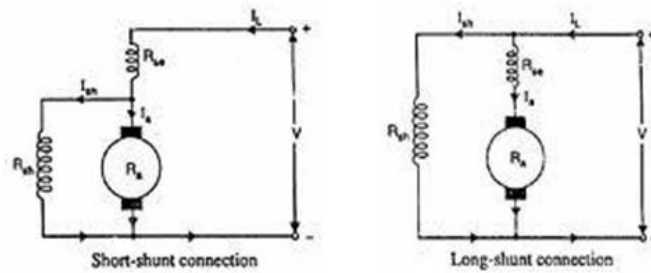


Figure 42. Electrical Engineering Community, 2013, Commutatively Compound Generator Equivalent Circuit, Sketch.

### 2.5.2 Classification base on the combustible Used

This chapter divides types of generators depending on the combustible used to function. Each one is explained with an example. It's important to consider that they may exist a lot of other types of generator, these are some examples of those interesting for this project.

#### Vegetable Oil Generator

ATG Vegetable Oil – Generators, Alternative Technology Group GmbH



Figure 43. ATG, 2012, ATG Multifuel 3SP Power Generator, Image

This operates with Straight Vegetable Oil (p.e SVO, rape oil, canola oil, colza oil, soya oil sunflower oil, palm oil, jatropha oil, etc.), Waste Vegetable Oil (WVO) or common Diesel Fuel. They can work alone or as backup system for a solar or wind power energy units, off – grid systems or electric – charging stations. Model ATG Multifuel 3SP (Figure 43) is portable and soundproof. Some Characteristics are shown in Table 17. ATG Multifuel 3SP Characteristics Table 17.

Straight Vegetable Oil (SVO) is different from diesel and is generally not recommended for long – term vehicles use because of its high viscosity and boiling point. It also has a negative impact on the engine lubricant. However, biodiesel can be made from SVO in a chemical reaction called transesterification that involves a reaction with methanol using caustic soda (NaOH). This alternative fuel has distinctive characteristics than SVO such as a lower viscosity and lower boiling point.

Waste Vegetable Oil is commonly used in a low scale production of fuel to generate energy. The most common used is the feedstock oil. The main problem using this type of oil are the emulsion and low-quality conversion when making biodiesel. It may contain water and that is dangerous for the conversion to biodiesel. The first thing that's needed to be done is know if the oil is dry or wet, and if it is wet, then separate both components.

There are three fundamental ways to dry WVO before the process. The first is mechanical separation, the second is chemical separation and the third and last is the vapor separation.



Mechanical separation will generally remove only free water, but not dissolved water. Vapor separation will remove all water in the oil but it is not the best way to do it. Boiling water uses a lot of energy to heat the oil to dangerously feverish temperatures and is not efficient. Even though, using WVO or SVO to generate fuel is one of the best ways to reuse waste. However, it is important to consider manufacturer recommendations and possible emissions generated.

Continuous Power (Maximum Power)	2.8kW when cos phi 1 (3kW)	
Nominal Voltage (Nominal frequency)	230 VAC (50 Hz)	
Maximum Current	13 A	
DC Output	12 V /8.3 A included and overload protection	
Diesel/heating oil tank	12 L	
Veg Oil tank	12 L (external, included delivery)	
Dimensions – Weight	L 720 x W 480 x H 630 mm – 106 kg (battery included)	
Others	Alarm	96 dB
	Engine Type	1 cylinder, 4 stroke, air cooled and direct injection
	Running Time at full tank	12 hours at 1kW

Table 17. ATG Multifuel 3SP Characteristics

<http://www.genset-gelec.com/vegetable-oil-generator/> Product

#### Biomass Generator

Biomass can be converted into electrical power through several methods, the most common is the direct combustion. Raw materials are agricultural waste or woody materials. On the one hand, biomass has an important advantage: it is available when needed and it is completely controllable. On the other hand, biomass combustion produces hazardous emissions, which must be controlled to comply with legal requirements. Also, needs fuel that must be procured, delivered, stored, and paid for. All these stages have also legal requirements that must be complied.

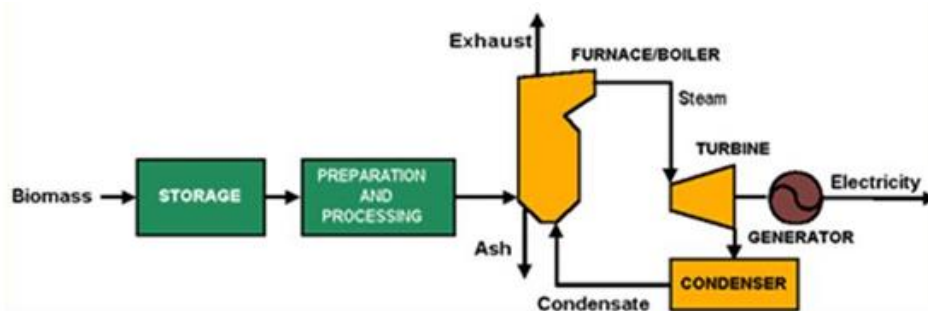


Figure 44. WBDG, 216, Direct Combustion/Steam Turbine System for Electricity Generation, Diagram

In a direct combustion system (Figure 44), biomass is burned in a combustor that generates hot gas. This feed a boiler and generate steam, which expands through a steam engine and produce mechanical or electrical energy.

Commonly, these generators as well as natural gas or propane generators are manufactured in Europe with outputs from 2kW to several MW.

Generally, biomass generators are ready for farms or big industries. They need its installation to function. What this project needs is a mobile unit. As an alternative, there's a gasifier generator

(Figure 45) that burns biomass and generates fuel. This device is connected to a generator based on fuel and finally electricity is obtained.



Figure 45. LEAF Generator, 1999, Gasifier, Image.

The product is design and manufactured by an American firm. Its power goes as high as 10kW. Its technology is known as *syngas* or *wood – gas*.

## 2.6 CHARGE CONTROLLER

A charge controller is a device that regulates the current and voltage of a power source (solar modules or wind turbines) to make them suitable for the battery, preventing its overcharging. For off grid power systems, when battery voltage rises to a pre-set maximum, where the battery is completely charged, the control automatically reduces or stops the charge.

Charge controllers are specified by their maximum charging current, battery voltage and whether they operate at the maximum input power. Some charge controllers are simple, but most include some other features like volt & amp meters, voltage conversion, low battery load disconnect or night light timer.

There are differences between solar charge controllers and charge controllers used for wind turbines, so that a solar charge controller is not applicable for wind turbines. Nevertheless, there are currently in the market charge controllers designed for both wind and solar energy systems.

### 2.6.1 Solar Charge Controllers

There are two main types of solar chargers: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking). The PWM controller is a switch that connects a solar array to the battery. When the battery is charged, the PWM disconnects the solar array to avoid overcharging.

The MPPT controller is more sophisticated, it adjusts its input voltage to get the maximum power from the solar array and then transform this power to supply the varying voltage requirement of the battery plus load. Unlike the PWM controller, the MPPT charge controller is a DC-to-DC transformer, which can transform power from a higher voltage to a lower voltage.

The effect of temperature must be taken in consideration in MPPT controllers. As it has been explained in previous chapters, the temperature affects in the solar panel performance, thus the maximum power point changes with the temperature.

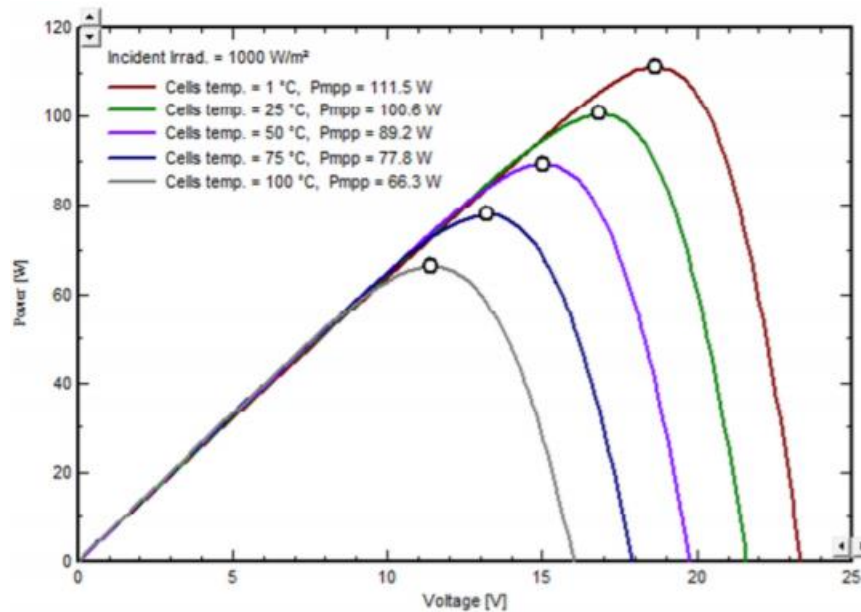


Figure 46. The Maximum Power Point moves to the left and downwards with the increasing temperature ([www.victronenergy.com](http://www.victronenergy.com))

## 2.6.2 Wind turbines charge controllers

A charge controller for a wind turbine not only has to protect batteries from overcharge, just like a PV charge controller, but also must keep a load on the generator always to prevent the turbine from over-speeding. Therefore, instead of disconnecting the generator from the battery (like most PV controllers) it diverts excess energy to a load – usually called dump-load – that absorbs the power from the generator. That load is normally a heating element.

## II. Preliminary Designs

### 1 SPECIFICATIONS AND FIRST DESIGNS

The MREU requires certain characteristics such as toughness, mobility, easy to handle for the operator and, as it is mobile, it has also to be prepared to function in any kind of path or place. The unit must be able to unfold itself when needed and fold when it's not necessary anymore.

In order to achieve these specifications, some mechanical and structural notions must be taken into consideration. Even though, before creating a MREU we have decided to study some simplified designs. This way we can compare them and draw some conclusions.

In addition to these mechanical specifications, the unit must cover between 3kW and 9kW and its floor area should measure approximately 2x4 meters.

Heeding these specifications, first ideas were thought and afterwards drawn in order to evaluate them. Despite being only very preliminar designs, the data of the solar panels (dimensions and output power) have been taken from *VictronEnergy* catalogue in order to make the designs as real as possible. The first design is shown in Figure 47 and Figure 48.

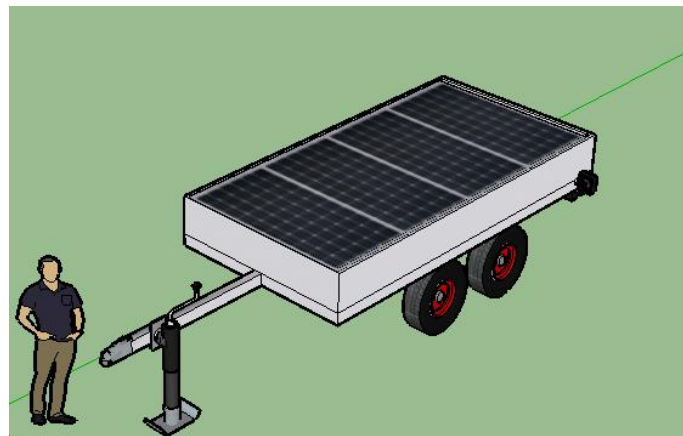


Figure 47. MREU folded – Design 1

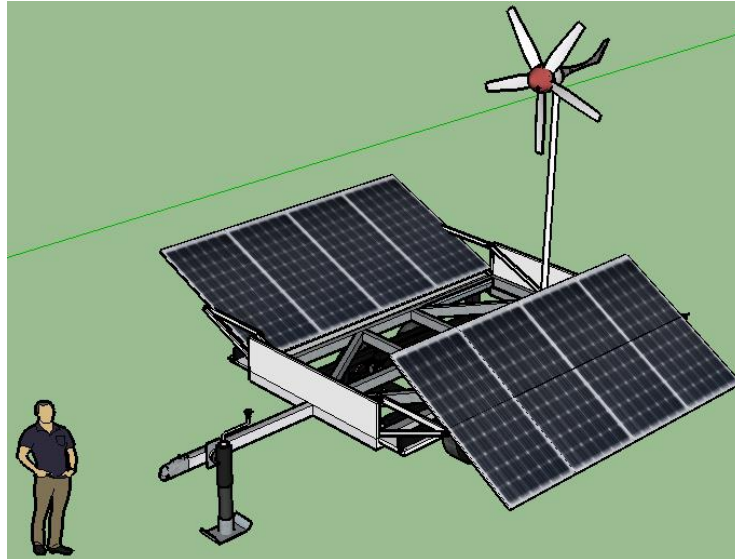


Figure 48. MREU unfolded - Design 1

This trailer unfolds itself in a symmetric way. It has eight solar panels of 300W each one and a dimension of approximately 2x1m. First the solar panels elevate and rotate until reaching a 30° inclination. Afterwards, the wind turbine lifts until reaching a perpendicular position with the trailer floor. Inside the trailer are placed the electronic gadgets such as the inverter, the generator, and the batteries.

Another design – shown in Figure 49 and Figure 50 - was done in order to consider different options. The second one is bigger and so it can hold more panels, thus it has more power.

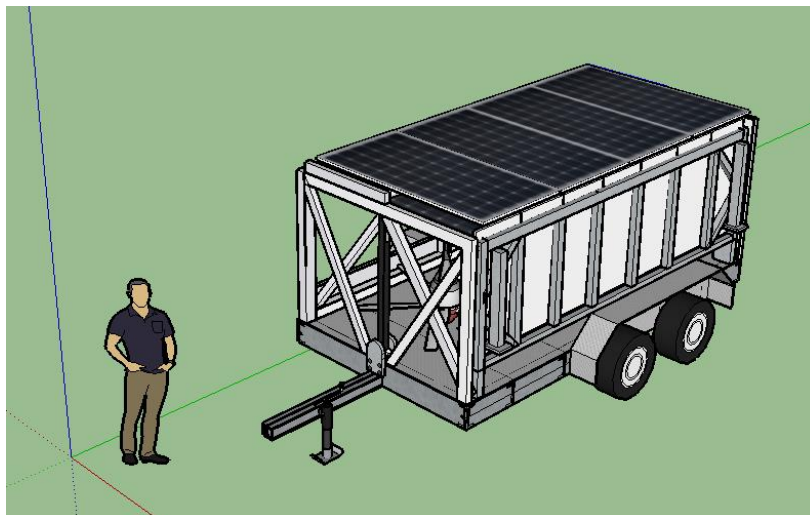


Figure 49. MREU Folded – Design 2



Figure 50. MREU unfolded - Design 2

## 1.1 COMPARISON

Both designs are very similar. The main ideas of the units are that they have both solar and wind source, and it can fold and unfold itself when needed. The main difference between both designs is the number of solar panels they have, which has a direct effect in the output power.

Considering only the power of the solar panels – as it is difficult to estimate an output power for the wind turbine and it should be similar in both designs – design number 1 has an output power of approximately 2.4kW, while design number 2 has 3.5kW since it has 11 more panels of 100W each one.

Another significant difference between both designs is the structure. The first design has a simpler structure but probably weaker, whereas the second one looks stronger and more stable. It should also be taken into consideration that it has to be built, so the final design should be as simple to build as possible. Table 18 describes pros and cons of each design.

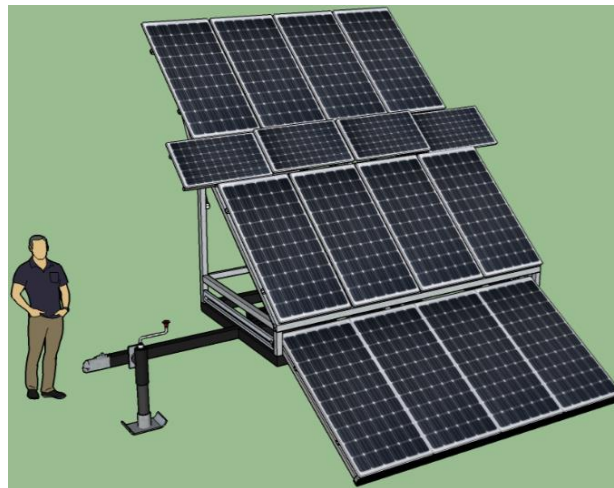
Design 1	
Advantages	Limitations
<ul style="list-style-type: none"> <li>- Simpler structure</li> <li>- Smaller and more compact</li> </ul>	<ul style="list-style-type: none"> <li>- Possible instability due to the wind turbine</li> <li>- Shadows in the solar panels due to the wind turbine</li> </ul>
Design 2	
Advantages	Limitations
<ul style="list-style-type: none"> <li>- More stable</li> <li>- More power generated</li> </ul>	<ul style="list-style-type: none"> <li>- Possible shadow apparition in the lower panels</li> </ul>

Table 18. Comparison between Design 1 and 2

## 2 THE ALTERNATIVE

Although the second design seems to be better, it has still some important disadvantages so we decided to draw a third one. This one tries to correct the disadvantages of the previous ones and carries the best characteristics of the first and second designs.

Design number 3 has a triangle structure which is fixed. The upper structure folds itself generating a triangle and the little pv panels fold themselves in two groups. The PV panels in the low part they fold themselves as a drawer.



*Figure 51. MREU unfolded - Design 3*

The structure of this model is simpler and more stable and it can hold a lot of panels as well, so its output power is still high. However, there are several difficulties in building this design. On the one hand, the drawer is conflicting with the storage of the devices inside the triangular structure. As well as the incompatibility of folding PV panels with each other for the risk of damaging themselves. On the other hand, the sliding mechanisms of the lower panels and the small ones increase the difficulty when building the structure.

The output power in this model would be 4kW, as it would have 12 panels of 300W and 4 of 100W. We discard the idea to put a wind turbine, as it is complicated to place it and we didn't find many wind turbines with the dimensions we needed in the market. So, we thought it is better to focus on the PV panels and put as many as possible.



# III. Photovoltaic System Design

In this chapter, we are going to describe all the devices of the photovoltaic system, how they will be connected and the reasons why. We are also going to define the model we have of each device and its characteristics, and to do some calculations to justify the model we have fulfilled the necessities of the system.

## 1 PV MODULES

The solar PV generator consists of 12 solar panels from Aleo Solar of 300 W each. Therefore, the system has a total power of 3,600 W. The main electrical characteristics of the panels are shown in Table 19. The complete datasheet can be found in Annex V.

Aleo S19 SOL_300					
Voltage (V)	Nominal power ( $P_{MPP}$ ) [W]	Max-Power Voltage ( $V_{MPP}$ ) [V]	Max-Power Current ( $I_{MPP}$ ) [A]	Open-Circuit Voltage ( $V_{oc}$ ) [V]	Short-Circuit Current ( $I_{sc}$ ) [A]
24	300	31.2	9.63	39.4	9.97

Table 19. PV Modules Characteristics

### 1.1 CALCULATION OF THE ENERGY PRODUCED

In order to calculate the energy produced by the PV panels it is necessary to know the existing mean Solar Irradiance of the place where the system is located. In this case, we consider Belgium as the geographic situation. The data has been obtained from The Solar Electricity Handbook website, by *Greenstream Publishing*. The parameters for obtaining the data are summarized in Table 20:

<b>Country</b>	Belgium
<b>Town / city</b>	Brussels
<b>Solar Panel Direction</b>	Facing South
<b>Inclination</b>	54° to the vertical axis

Table 20. PV Data (Belgium)

The angle of inclination is 54° to the vertical axis, as it is the closest value to the trailer's one, which will be around 30° to the horizontal axis.

Brussels Average Solar Insulation (Measured in kWh/m <sup>2</sup> /day)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.33	2.13	3.02	3.93	4.77	4.79	4.80	4.54	3.43	2.41	1.50	1.07

Table 21. Brussels Average Solar Insulation.



From this information, it is possible to calculate the **average insolation** per year:

$$\text{Mean Solar Irradiance per year} = \frac{\sum \text{month data}}{12} = 3.14 \frac{\text{KWh}}{\text{m}^2 \text{day}}$$

If this value is divided by  $1 \text{KW/m}^2$ , which is the irradiance in Standard Test Conditions (STC), we obtain the number of Peak Sun Hours (PSH). This is the number of hours of irradiation per day considering a constant irradiance of  $1000 \text{ W/m}^2$ .

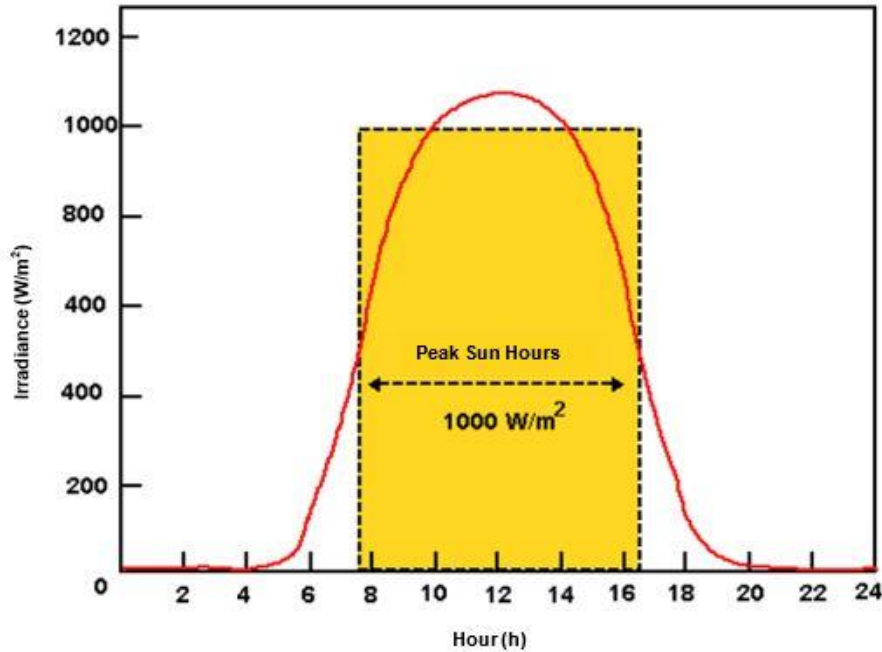


Figure 52. Calculation solar Blog, 2014, Diagram.

Once we have the number of peak solar hours, we can calculate the energy provided by the solar system:

$$E(\text{KWh}) = P(\text{KW}) \cdot t(\text{h}) = 3.6 \cdot 3.14 = 11.3 \text{ KWh}$$

## 2 BATTERIES

To calculate the capacity of the batteries needed, we have considered the system should be able to accumulate, at least, the energy generated in one day. Therefore, that means a capacity of 11.3 kWh.

The battery not only has to allow a certain number of days of autonomy, but also should not be discharged over a certain Depth of Discharge (DOD). In this case, we consider a DOD of 80%, as it is a common value for Deep Cycle Batteries. Hence, the battery's capacity is:

$$E_{\text{bat}} = \frac{E_{\text{demand}} \cdot n_{\text{autonomy}}}{\text{DOD}}$$

In this case,

- $E_{\text{demand}} = 11.3 \text{ KWh}$
- $n_{\text{autonomy}} = 1$
- $\text{DOD} = 0,8$

Accordingly,  $E_{bat} = \frac{11.3 \cdot 1}{0.8} = 14.125 \text{ KWh}$

However, from the above the battery's capacity is given in kWh, while batteries are offered in Ah-capacity  $C_{bat}$ . In consequence, the  $C_{bat}$  from the  $E_{bat}$  and the voltage of the battery is determined.

$$C_{bat} = \frac{E_{bat}}{V_{sys}} = \frac{14,125 \text{ Wh}}{48 \text{ V}} = 294.27 \text{ Ah}$$

At last, we have four AGM Super Cycle Batteries at our disposal, from Victron Energy. Their characteristics are shown below in the Table 22, the complete datasheet can be found in Annex VI.

Article number	Voltage (V)	Ah C5	Ah C10	Ah C20	I x w x h (mm)	Weight (Kg)
BAT412123081	12	200	210	230	532 x 207 x 218	61

Table 22. Batteries Characteristics

As the nominal voltage of each battery is 12 V, and the system DC voltage is 48V, the four batteries will have to be connected in series to reach the voltage needed. With all four batteries, the total capacity will be 11,040 Wh. Despite this value is a little lower than the one previously calculated, it is enough for accumulate the energy produced per day.

### 3 SOLAR BATTERY CHARGER

The Solar Battery Charger must fulfil the following characteristics:

- It must accomplish the system's voltage ( $V_{sys}$ ). Hence, in this case the solar charge controller must be able to work at a  $V_{sys} = 48\text{V}$ .
- Its maximum input power has to be higher than the power of the PV array. According to standard practice, the maximum input current that the solar charge controller can accept should be, at least, 1.2 times the short – circuit current ( $I_{sc}$ ) of the PV array.

It is not a problem to find in the market a Solar Battery Charger which can work at 48V. The most problematic parameter is the input power that the controller can support. In order to know which model of Solar Battery Charger choose, and if more than one would be needed, it is necessary to calculate the total  $I_{sc}$  of the PV system. This value can be found with the following expression:

$$Total I_{sc} = n_{branches of panels} \cdot I_{sc_{panels}}$$

As the previous equation describes, the more number of branches there are, the higher is the value of the output current of the PV array.

There are at our disposal three solar charge controllers from Victron Energy, with the following characteristics:

<b>Model</b>	BlueSolar Charge Controller MPPT 150/35
<b>Battery voltage</b>	12 / 24 / 48V
<b>Rated charge current</b>	35 A
<b>Nominal PV power</b>	12V: 500W / 24V:1000W / 36V: 1500W / 48V: 2000W
<b>Max. PV short circuit current</b>	40 A
<b>Maximum PV open circuit voltage</b>	150V absolute maximum coldest conditions 145V start-up and operating maximum

Table 23. Controller Characteristics

Considering the characteristics of Table 23, it is necessary to set the best configuration of the PV array for the good operation of the entire system. This is explained in the next chapter. The complete datasheet can be found in Annex VII.

## 4 PV ARRAY CONFIGURATION

Since in this case we have 12 panels, there are different series – parallel combinations to connect them. Therefore, the voltage and the value of the  $I_{sc}$  will be different depending on how the panels are connected. As we have three Solar Charge Controllers, the PV panels will be connected by groups of four to each solar charger. There are mainly two different options:

- a) 2 branches in parallel, each one formed by 2 panels connected in series.

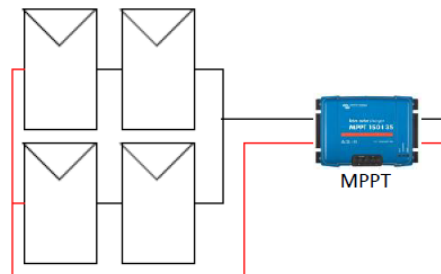


Figure 53. PV Parallel configuration

With this combination, the voltage would be 48V, as each panel voltage is 24V and there are two panels connected in series in each branch. The calculations are shown below:

$$Voltage = n_{panels\ in\ series} \cdot V_n = 2 \cdot 24 = 48\ V$$

The total short-circuit can be calculated as it has been described before:

$$Total\ I_{sc} = n_{branches\ of\ panels} \cdot I_{sc_{panels}} = 2 \cdot 9.97 = 19.94\ A$$

A factor of 1.2 is normally applied for safety reasons. Hence, the current that the solar charge controller should resist is, at least:

$$I_{sc}^* = 1,2 \cdot I_{sc} = 1.2 \cdot 19.94 = 23.93\ A$$

All the characteristics of each PV array connected to one charger using this configuration are shown in the table below:

Aleo S19 SOL_300					
Voltage (V)	Nominal power ( $P_{MPP}$ ) [W]	Max-Power Voltage ( $V_{MPP}$ ) [V]	Max-Power Current ( $I_{MPP}$ ) [A]	Open-Circuit Voltage ( $V_{oc}$ ) [V]	Short-Circuit Current ( $I_{sc}$ ) [A]
48	1,200	62.4	19.26	78.8	19.94

Table 24. PV Panels Characteristics

b) 4 panels connected in series

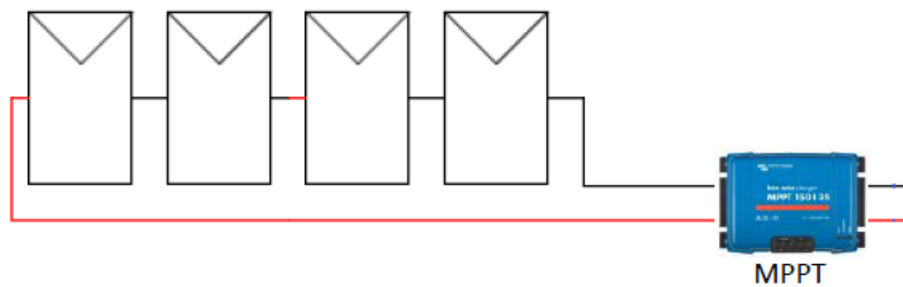


Figure 54. Series Configurations

In this case the voltage is:

$$\text{Voltage} = n_{\text{panels in series}} \cdot V_n = 4 \cdot 24 = 96 \text{ V}$$

And the total short-circuits current:

$$\text{Total } I_{sc} = n_{\text{branches of panels}} \cdot I_{sc_{\text{panels}}} = 1 \cdot 9.97 = 9.97 \text{ A}$$

$$I_{sc}^* = 1,2 \cdot I_{sc} = 1,2 \cdot 9.97 = 11.96 \text{ A}$$

Even though with this combination the current is much lower, as it is the half of the first combination, the voltage is higher because it has more panels connected in series.

All the characteristics each PV array connected to one charger using this configuration are shown in the table below:

Aleo S19 SOL_300					
Voltage (V)	Nominal power ( $P_{MPP}$ ) [W]	Max-Power Voltage ( $V_{MPP}$ ) [V]	Max-Power Current ( $I_{MPP}$ ) [A]	Open-Circuit Voltage ( $V_{oc}$ ) [V]	Short-Circuit Current ( $I_{sc}$ ) [A]
96	1,200	124.8	9.63	157.6	9.97

Table 25. PV Panels Characteristics

Normally it is better to have less current and more voltage, since the higher current is, the higher will be the electric losses. Thus, the second configuration, which has only a unique branch with all four panels in series, should be better in terms of the current.

However, the total Open-Circuit voltage of the PV array using this configuration is 157.6 V, which is higher than the value permitted by the Solar Charge Controller, which is maximum 150V (see Table 23 and Table 25). So, for this reason is not possible to connect the four panels in series and we have to connect them in two branches, as it has been described in the section a). The complete PV array connected to the three chargers is illustrated in the drawing below:

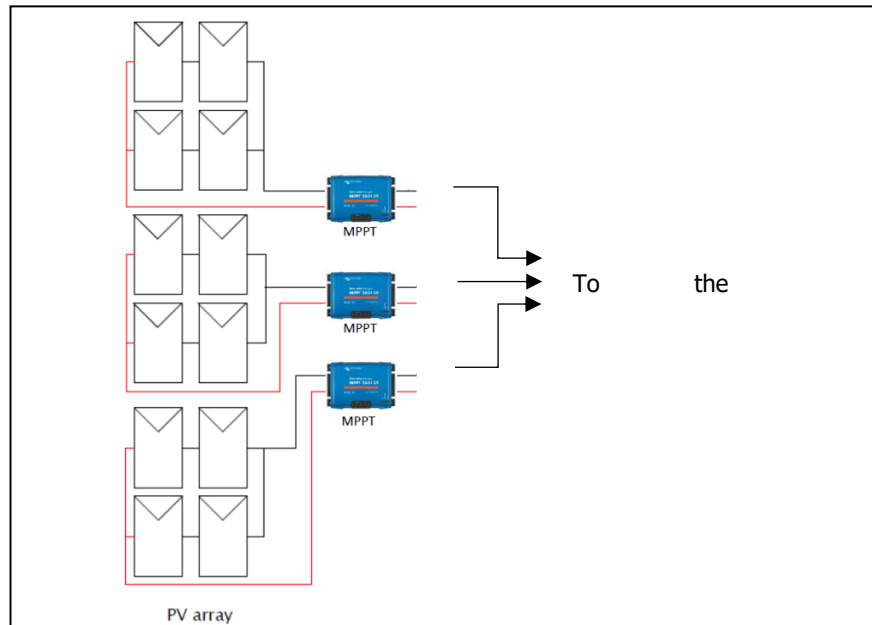


Figure 55. PV array drawing

## 5 INVERTER

There is at our disposal the *Victron Multiplus 48/3000/35 Inverter/Charger*, from Victron Energy. (find complete datasheet in Annex VIII). With this device is not only possible to convert the DC current in AC current, but also to have an AC source which supplies energy when the DC source is not enough.

Main technical characteristics of *Multiplus* are shown below:

INVERTER	
<b>Output</b>	230 VAC, 50Hz
<b>Output power (at 25°C) (VA)</b>	3000
<b>Output power (at 25°C) (W)</b>	2400
<b>Peak power (W)</b>	6000
<b>Maximum efficiency (%)</b>	95
<b>Zero load power (W)</b>	25

CHARGER	
Charge current house battery (A)	35
Auxiliary output	Yes (16A)
Programmable Relay	Yes
Protection	<ul style="list-style-type: none"> <li>- Output short circuit</li> <li>- Overload</li> <li>- Battery voltage too high or too low</li> <li>- Temperature too high</li> <li>- 230 VAC on inverter output</li> <li>- Input voltage ripple too high</li> </ul>

Table 26. Inverter Characteristics

There are several uses and configurations for the *Victron Multiplus*. In this case, it will be used mainly as an inverter, but also it will work as an automatic switch to connect the generator to the system when the batteries are low, or they have not enough power. When the generator is connected, it provides energy to the AC loads and charge the batteries with the remaining energy.

In the illustration (Figure 56) below it is shown, in a simplified way, how the Multiplus Inverter/Charger is connected with the other devices.

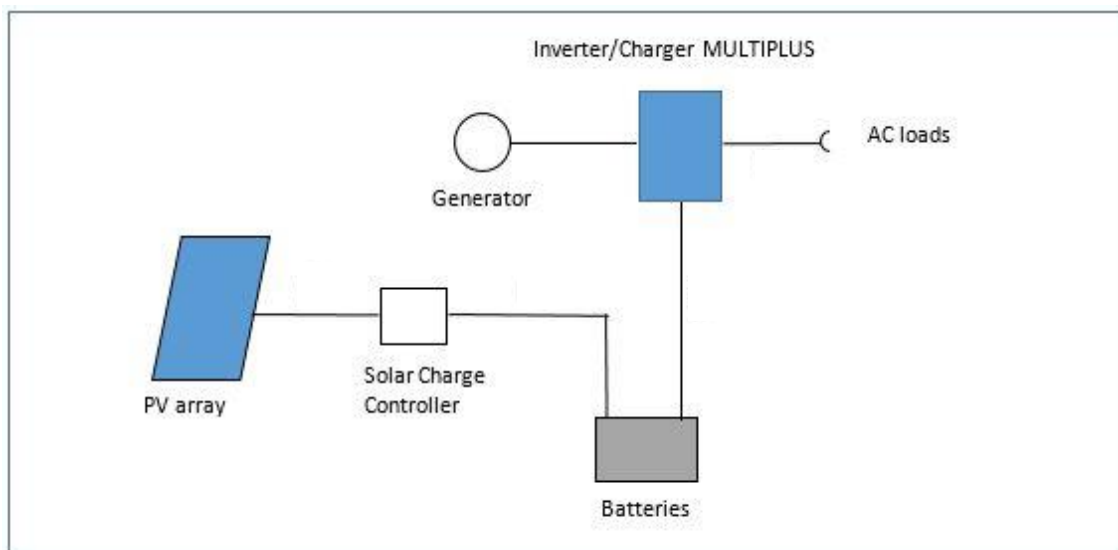


Figure 56. Connections between electric devices, drawing

## 6 OTHER DEVICES AND CONNECTIONS BETWEEN THEM

Apart from the main devices of the PV system that have been explained in the previous section, in this case there will be other devices which are described below.

### Victron Battery Balancer



The Battery Balancer equalizes the state of charge of two series connected 12V series, or of several parallel strings of series connected batteries. As there are four batteries in series, three Battery Balancers will be needed to make sure that the state of charge is balanced and so prevent that the batteries life gets shorter.

### Orion-Tr 48/12 -20 (240W) DC-DC converter



The function of this device is to convert de DC current at 48V to 12V.

### Lynx distribution system



Lynx Shunt



Lynx Distributor

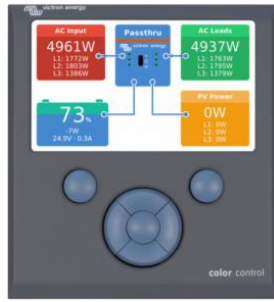
This system is used for connecting the panels and the batteries in a safety way, and also it monitors some electric parameters. The distribution system consists on two devices: Lynx Shunt and Lynx Distributor. The first one is an intelligent 1000A shunt with a fuse, and it can monitor the state of charge of the battery. The second one is a bus bar, with four DC fuses. It monitors the status of each fuse and indicate its condition with a LED.

### Battery Protect



The function of Battery Protect is to disconnect the battery from the loads before it gets completely discharged (which would damage the battery) or before it has insufficient power left to crank the engine.

### Color Control GX



The Color Control GX provides control and monitoring for other devices connected in the system, such as the Inverter/Charger, the Solar Charger, and the Lynx distribution system. It not only displays the information that comes from these devices, but also control and let configure a lot of parameters of the system. It can also be connected to internet so that one can see all the information remotely.

After knowing all the devices of the PV system, the next step is knowing how to connect them. In annex 4 it is shown the complete electrical diagram where one can see how will be the connections between the devices.

It is necessary to know which wire section is needed. In order to know it, it is possible to make some calculations with the current passing through it and the maximum voltage drop that can be admitted.

However, in some devices a certain section is already recommended or set by the manufacturer. Thus, in that case no calculations will be needed.

## 7 WIRING

It is necessary to know which wire section is needed. In order to know it, it is possible to make some calculations with the current passing through it and the maximum voltage drop that can be admitted. However, normally for each device a certain section is already recommended or set by the manufacturer.

In this case, Victron Energy recommends using cables of 50mm<sup>2</sup> for connecting the batteries to the inverter. The section of the wire between this two devices is that large due to the high current between them. As the output power of the inverter is 3000W and the voltage of the batteries is 48 V, we can calculate the current of this section:

$$I = \frac{P_{INV}}{V_{sys}} = \frac{3000}{48} = 62,5 \text{ A}$$

Due to this value of current and taking into account that the voltage drop in this section should be of 1% at maximum, a section of 50mm<sup>2</sup> is justified.

The power terminals of the BlueSolar Charge Controller let a section of 13mm<sup>2</sup>, as well as the Orion-Tr DC-DC Converter. And the terminals of the battery balancer are for wires of 6mm<sup>2</sup>. Therewith, all the wiring needed is determined.



## IV. Structural Design and calculations

### 1 OBJECTIVE

Before starting to build the final structure, we started designing a prototype. The aim of this prototype is to ensure that the design doesn't fail once built. Also know the parts that need to be reinforced. Furthermore, the prototype will be also useful to ameliorate the design once the assembly is done. Thus, once the final construction on the trailer is made, almost all corrections will have been already applied in the prototype.

### 2 PROCESS & RESULTS

At the beginning, we didn't know which type of PV panels we would use. Therefore, the preliminary designs are just sketches without exact dimensions. At this point of the designing process we already know the dimensions of the PV panels and their geometrical characteristics.

Accordingly, we have made some sketches with dimensions to check the availability of our design. The drawing shown in Figure 57 shows the structure profile. Since it's only a prototype, the figure only shows the basic dimensions and the general geometry.

This is a right – angled triangle with an angle  $57^\circ$  from the horizontal axis, a height of 2626 mm and a width of 1980 mm. There is a beam within 840 mm to reinforce the structure so that can support the weight of the PV panels. The structure folded has two lines of PV panels and unfolded has three. However, in the drawing below only the fixed structure is shown and not the unfolding part which holds the third line of panels. (See the complete drawing with all the dimensions in Annex I).

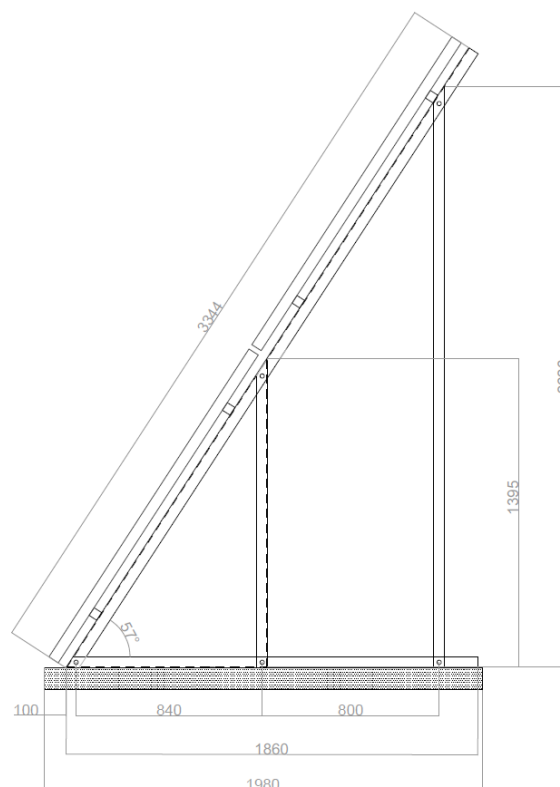


Figure 57. Right - angled triangle structure (folded), CAD drawing

Even though this structure seems to be good, especially for its simplicity, after doing some analysis on it we concluded that this type of triangular structure is not suitable because of several reasons. The most important one is the danger of falling when there's too much wind or driving too fast. It is also wrong because it's too tall when it's folded and the angle is too high. To undertake somehow these problems, we would need to add an extra weight to stabilize the MREU.

In conclusion, this structure is dangerous and unstable due to its height. It is also low efficient due to the large angle of  $57^\circ$ . For all this, we refuse to use this structure for our Mobile Renewable Energy Unit.

As an alternative, we decided to use a trapezium instead of a right – angled triangle (see Figure 5). With this geometry, the structure has a better stability and it is not as high as the previous one. Moreover, the angle of inclination of the panels became around  $30^\circ$  instead of  $57^\circ$  thus, its efficiency increases. (See the complete drawing with all the dimensions in Annex II)

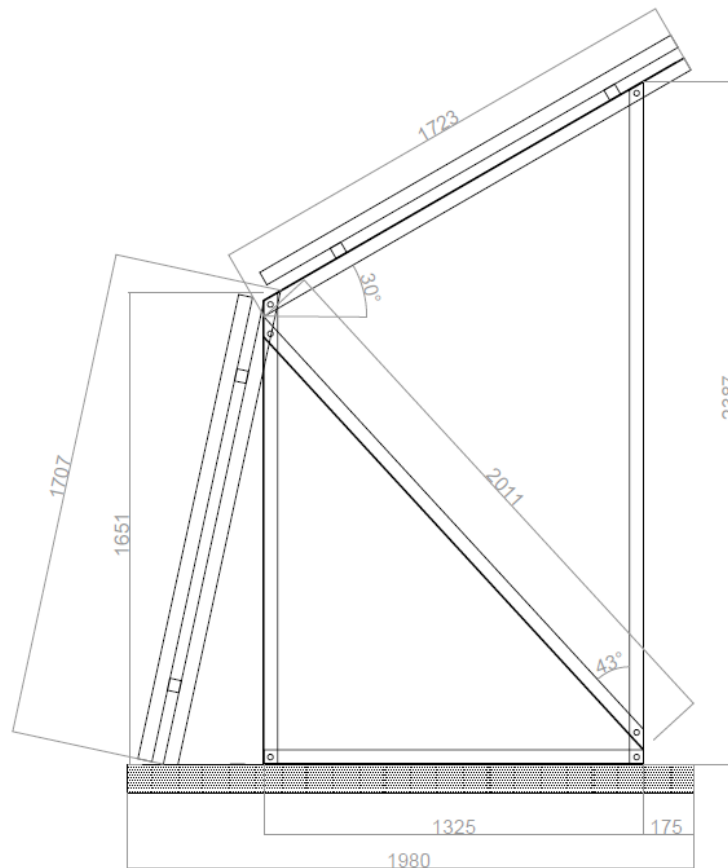


Figure 58. Trapezoidal structure profile (folded), CAD drawing

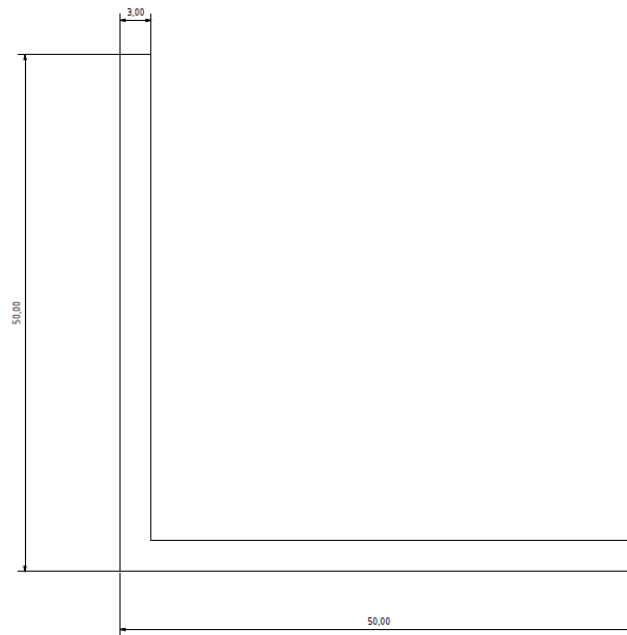
# V. Building process

## 1 TOOLS & MATERIAL

In the workshop, we had access to the following types of aluminum beams:

### **UNI EN 10056 – 1 50x50x3**

Used for the general structure. It is used for the vertical, horizontal, and crossed beams. Figure 1 shows the beam profile with its measurements.



*Figure 59. L profile drawing, Autodesk Inventor*

### **SOLAR PROFILE 41X41 2N180**

Used to hold the PV panels in the leaning parts. Two beams of this type hold a PV panel. Figure 60 shows some illustrative dimensions of the profile.

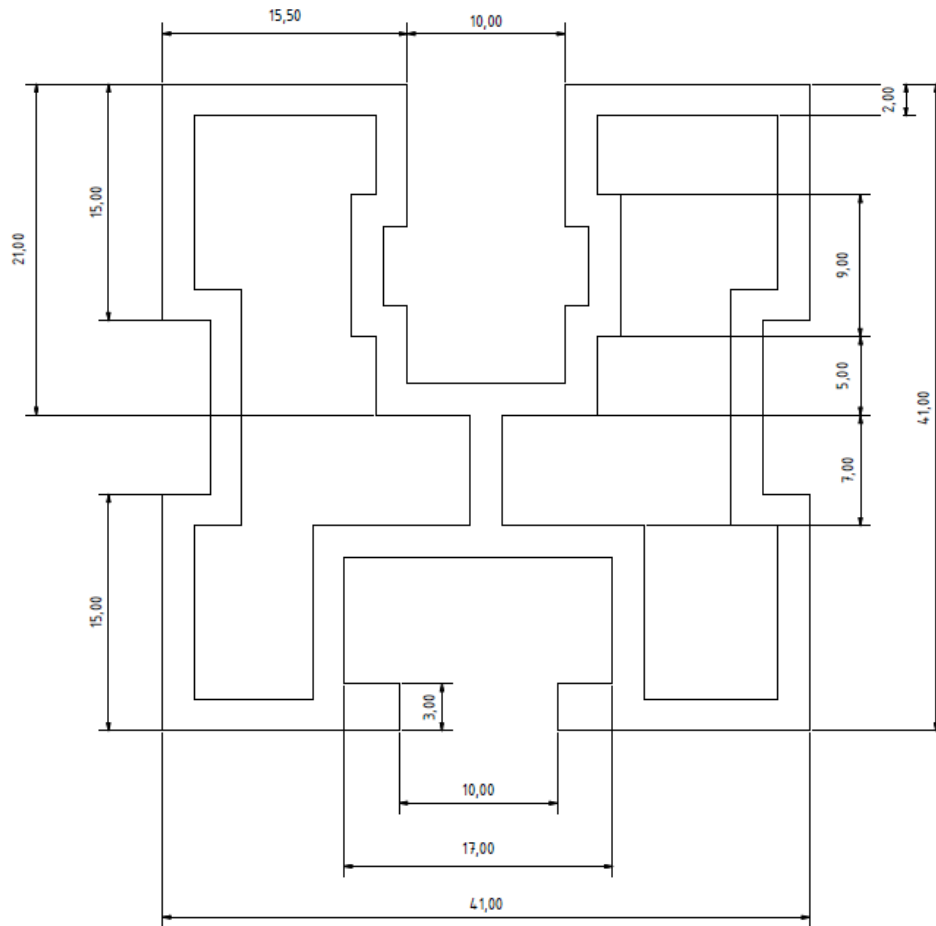


Figure 60. Solar Profile drawing, Autodesk Inventor

### ISO 1035/3 1980

This filled beam is used to reinforce certain parts of the structure. Due to the use of an L profile, the corners of the structure need to have a stronger part to hold the panels as well as hold itself.

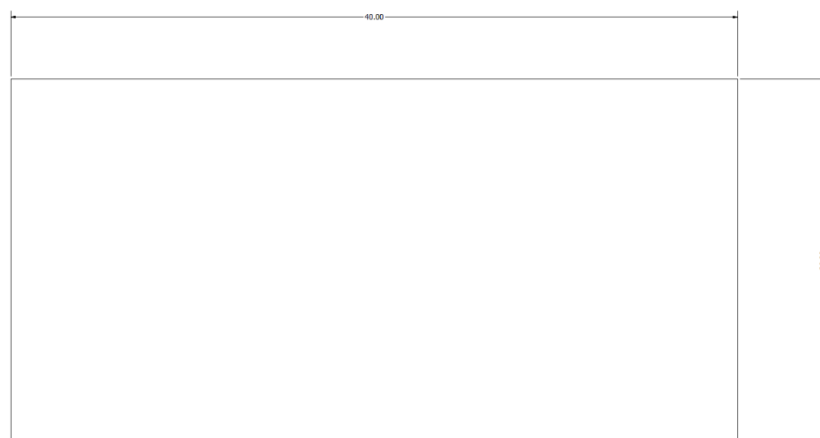


Figure 61. ISO Rectangular Profile, Autodesk Inventor

To manipulate the beams, we have used the tools shown in the following Images. The saw is from VM services (Image 1 and Image 2). Set Square (Image 3) and Protractor (Image 4) are from Stanley. Finally, the drill is from *Målilla* (Image 5), we have used bits of  $\varnothing 2\text{mm}$ ,  $\varnothing 5\text{mm}$  and  $\varnothing 10\text{mm}$ . To join the beams, we have used threads and screws.



Image 1. Automatic Saw, VM Service



Image 2. Automatic Saw, VM Service

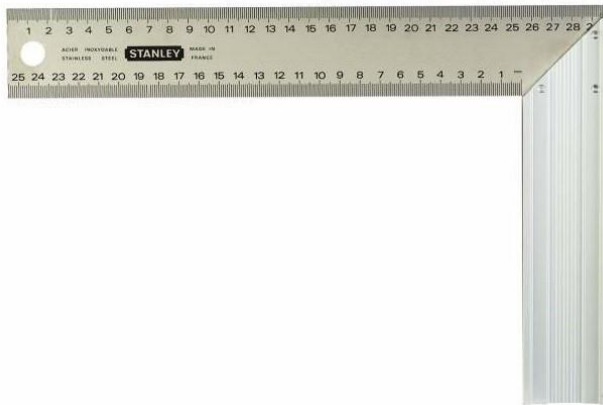


Image 3. Set – Square



Image 4. Protractor



*Image 5. Drilling Machine, IMA Malilla*

## 2 PROCEDURE

The procedure of building the new prototype was the following:

First, we measured the first trapezoid on the floor (as shown in Image 6) and after being sure about the angles and distances we drilled some holes to join the beams.



*Image 6. Trapezoidal Porch.*





*Image 7. Parallel Porches*

Image 7 shows the two exact arcades with the leaning part above them. On it we can find the two solar profile beams for the solar panels. The structure must hold three lines of PV panels. To reinforce it, we had to place the crossed beams in each porch, and between them. As well as ensuring the parallelism between the two arcades. Image 8 shows the crossed beams and the extensible structure of the inferior part of the prototype.



*Image 8. Prototype with crossed beams and first folding part*



*Image 9. Reinforced corner 1*



*Image 10. Reinforced corner 2*

Image 9 and Image 10 show how we reinforced all the corners of the structure.

After building the inferior bending part, we assembled the upper one. The procedure was the same as the previous one. As mentioned before, we also add the horizontal beams to ensure the parallelism between the porches (Image 11 – highlighted by the blue rectangles). Finally, the prototype finished is shown below in Image 12.



*Image 11. Final Prototype seen from the bottom*





*Image 12. Final Prototype unfolded*

Finally, after building the prototype, we made the final drawing with the exact geometry and dimensions. The drawing of the unfolded final structure profile can be seen in Annex III, with all dimensions needed for building it.

From the prototype, we started building the entire structure, which is formed by 5 porches. Firstly, we started numbering the beams of the prototype. Afterwards, we dismantled the prototype to take the beams as a model for cutting other beams with the same dimensions. Finally, we drilled all the holes needed in each beam.

For the vertical beams, finally we have used an L profile as the prototype, but with a thickness of 5mm instead of 3mm. This way the final structure will be stronger and more stable.

We cannot proceed with the construction of the structure as we do not have all the material at our disposal yet. However, we will try to explain the procedure we will use to build the complete structure.

Once we have cut and drilled all the holes in the beams, then we will only need to assembly them. For that, we firstly will mount the porches. We will put the beams on the floor in the right position, as we did with the prototype (see Image 6) and will put all the threads and screws to join all the pieces. After mounting all the porches, we will join them with the cross beams and the solar profiles as well.

Finally, we will put the pneumatic pistons in order to be able to unfold the panels at the back, as the system of a boot of a car.

### 3 ELECTRIC ASSEMBLY

We started building a casing to put all the devices and protect them. The casing is formed by four boxes, as a single box is too small to host all the devices. So, in each box there will be some of them.

To build the case we first drilled four holes between each box so that the wiring can pass through them. We also build metal sheets that fit the boxes in order to hold the devices there. Afterwards,

we cut two L profile beams which will hold the protecting case. Finally, we drilled the holes in those beams to join the case with them. Image 13. Building of the case process shows the four boxes tied to each other with some of the holes for the wires.



*Image 13. Building of the case process*

# VI. Conclusions

## 1 OUTCOME

At the beginning, we defined several goals such as building an engine able to provide energy using green energies and inspiring young generations in green energies development. To achieve them, we followed a process divided in Chapters. First, we made a market study in order to know what was already made, the characteristics that our MREU should have. After that, we made our first designs. It was the time for us to go wild in our imagination and let our creativity run wild.

Even we sketched our own designs, we had to adapt them to the resources we had to build it. We have noticed that in a designing process, sometimes it is more important the easiness of building than the appearance. Since it's an electric machine, we had also had to design the photovoltaic system with all the energy management devices that needed, considering the suppliers of the University. We had to readjust this design to the devices we finally had to our disposal.

Once that was done, it was time to start building a prototype. We had studied our resources and we had made a design that fitted in the demands and was structurally stable. The idea of building a prototype was to be sure that the structure holds itself before building it on the trailer, this way we could anticipate to any future possible structural problems. When we were sure about the structure we started preparing all the beams for the final building process. Meanwhile, we did the electric assembly, placing all the management devices in different boxes connected to each other.

Unfortunately, due to change of timings and shortcomings, we couldn't be able to finish building the MREU before presenting this project. A lot of materials were delivered later than we thought. Still, we have explained as detailed as we could the process that is needed to follow to finish building the structure and the electric assembly. In order to finish it, we will continue with the assembly of the trailer until the day of our departure.

## 2 CLOSURE

To sum up this project we would like to highlight how important was to us being part of a project like this. Having the opportunity to live all the processes involved in building the MREU gave us the chance to witness how different branches of engineering merged into one unique goal.

This project has also been a challenge to us because we had to implement the expertise learned during our degree. Furthermore, building the MREU has been a way to complement our academic education.

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## 2 WEBOGRAPHY

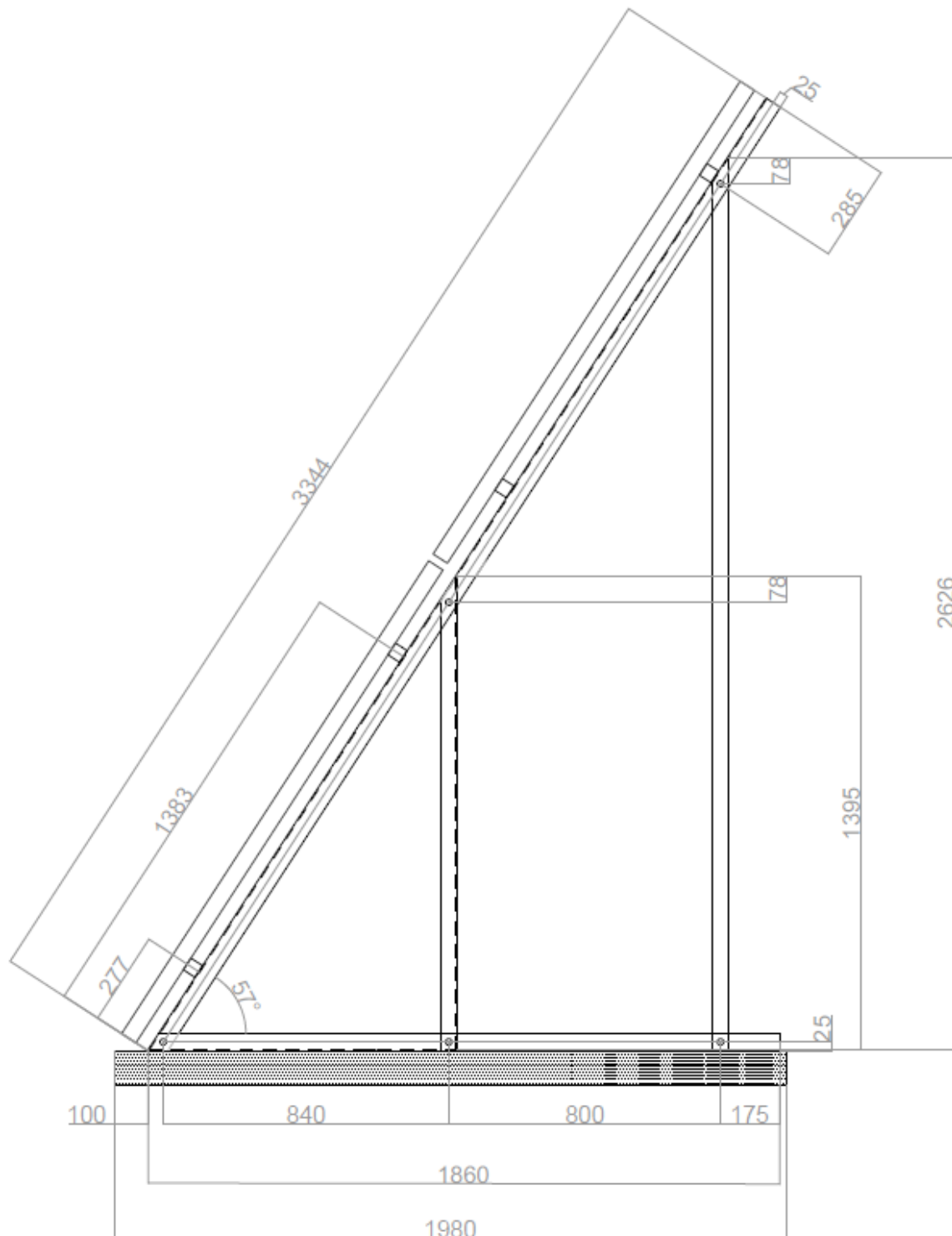
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## VIII. Annexes

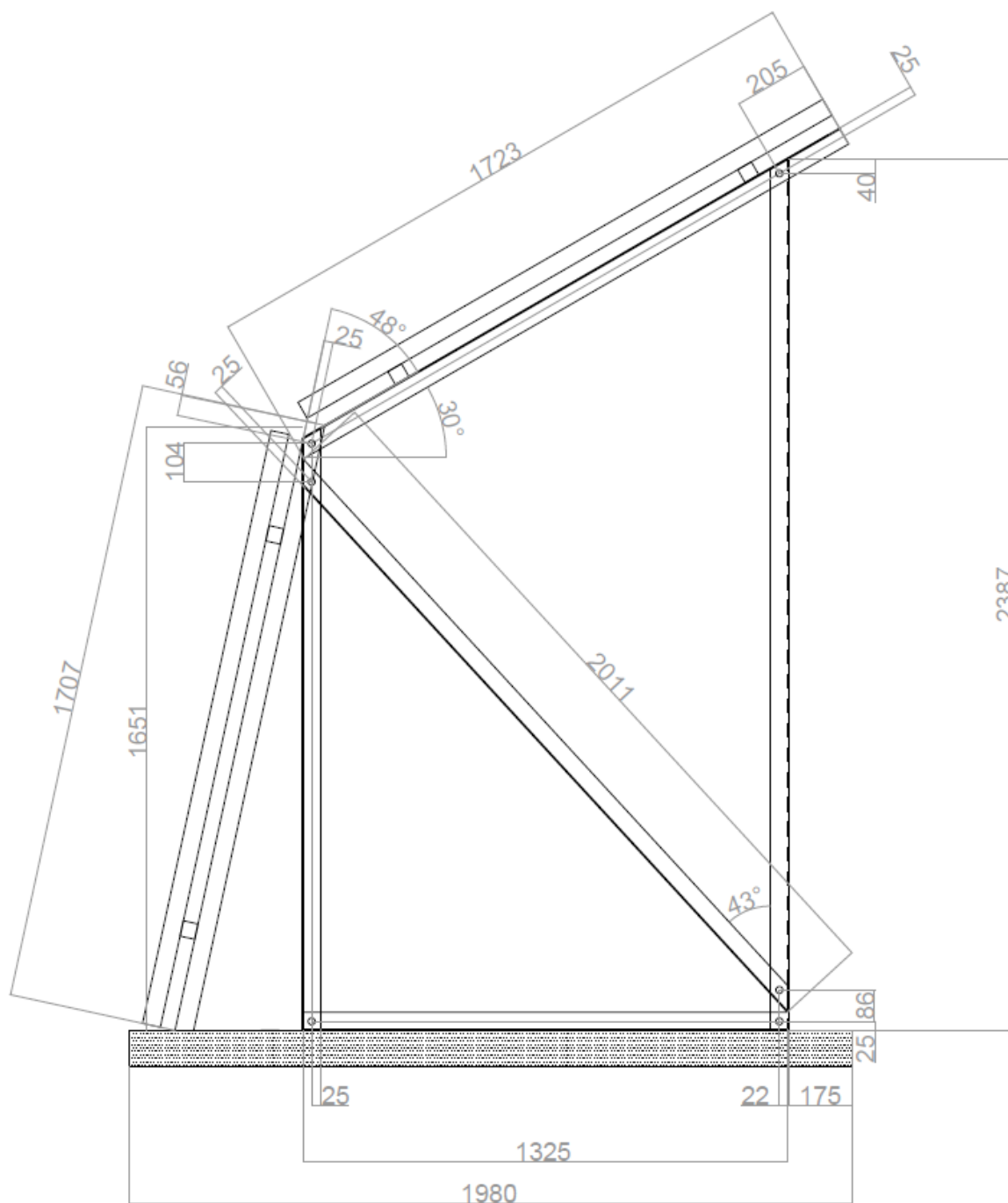
- I. Drawing of the right – angle triangle structure
- II. Drawing of the trapezoidal structure
- III. Drawing of the final unfolded prototype of the structure
- IV. Drawing of the electrical devices connection
- V. Aleo S19 PV panels datasheet
- VI. Victron Energy AGM Super Cycle Batteries datasheet
- VII. Victron Energy BlueSolar Charge Controller MPPT 150/35 datasheet
- VIII. Victron Energy Multiplus 48/3000/35 Inverter/Charger datasheet
- IX. Victron Energy Battery Balancer datasheet
- X. Victron Energy Orion Tr DC-DC converter datasheet
- XI. Battery Protect datasheet
- XII. Victron Energy Color Control GX datasheet

## I. Drawing of the right – angle triangle structure



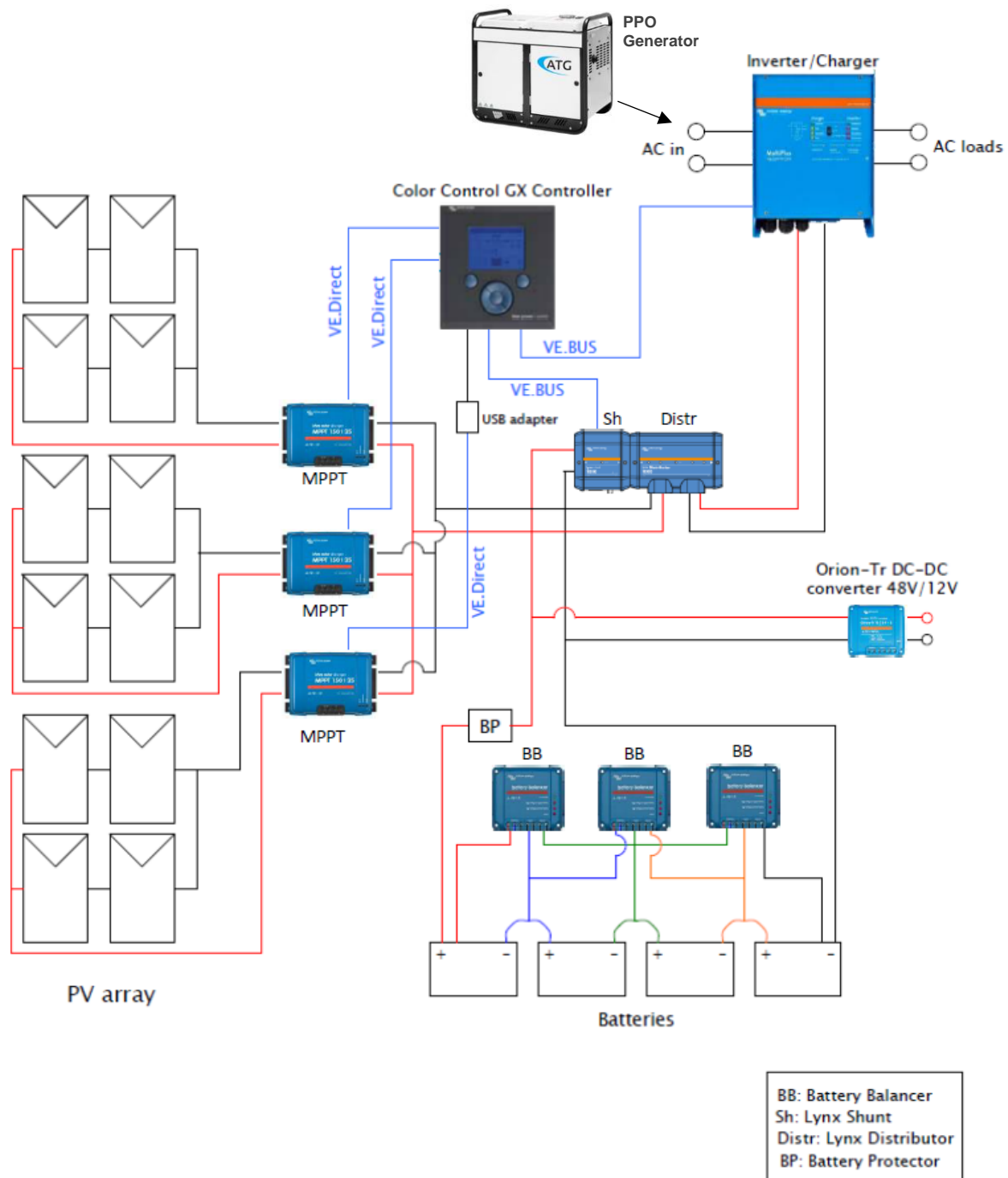


## II. Drawing of the trapezoidal structure



The image displays a set of architectural drawings for a roof structure. The main drawing is a plan view showing the layout of the roof with various dimensions and angles. Key dimensions include a total width of 1715, a section width of 1400, and a total length of 1720. The roof pitch is indicated as 31°. A detailed section A-A is shown, illustrating the structural components and their dimensions. Three detail sections are provided: Section B-B, Section C-C, and Section D-D, each showing specific structural details and dimensions. Section B-B shows a 30° angle and dimensions of 200, 105, and 300. Section C-C shows a 30° angle and dimensions of 200, 105, and 300. Section D-D shows a 45° angle and dimensions of 150, 100, and 1000. The drawings are labeled with 'SECTION A-A', 'SECTION B-B', 'SECTION C-C', and 'SECTION D-D'.

## IV. Drawing of the electrical devices connection



## **ANNEX V**

# **Aleo S19 PV panels datasheet**

## **ANNEX VI**

# **Victron Energy AGM Super Cycle Batteries datasheet**

## **ANNEX VII**

# **Victron Energy BlueSolar Charge Controller MPPT 150/35 datasheet**

## **ANNEX VIII**

# **Victron Energy Multiplus 48/3000/35 Inverter/Charger datasheet**

## **ANNEX IX**

# **Victron Energy Battery Balancer datasheet**



## **ANNEX X**

# **Victron Energy Orion Tr DC-DC converter datasheet**

## **ANNEX XI**

# **Battery Protect datasheet**

## **ANNEX XII**

# **Victron Energy Color Control GX datasheet**